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CHEMISTRY 30

MODULES 1-7
LEARNING FACILITATOR'S MANUAL

Distance Learning

Alberta
EDUCATION

CANADIANA

SEP 14 1995

Chemistry 30

LEARNING FACILITATOR'S MANUAL

Alberta
EDUCATION

NOTE: This Chemistry 30 Learning Facilitator's Manual contains answers to teacher-assessed assignments and the final test; therefore, it should be kept secure by the teacher. Students should not have access to these assignments or the final test until they are assigned in a supervised situation. The answers should be stored securely by the teacher at all times.

This document is intended for	
Students	
Teachers (Chemistry 30)	✓
Administrators	
Parents	
General Public	
Other	

Chemistry 30
Learning Facilitator's Manual
Modules 1-7
Alberta Distance Learning Centre
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Teachers

Register with the Alberta Distance Learning Centre

The Alberta Distance Learning Centre is dedicated to upgrading and continually improving your Learning Facilitator's Manual so that it accurately reflects any necessary revisions we have had to make in the student assignments or the sample final test. The types of revisions that will be made are those that make the course more accurate, current, or more effective.

The ADLC will send you the **latest enhancements or minor upgrades** for your Learning Facilitator's Manual if you return the following registration card to: Alberta Distance Learning Centre, Box 4000, Barrhead, Alberta, T0G 2P0, Attention: Instructional Design and Development.

ADLC Learning Facilitator's Manual
Registration Card

First Name	Surname
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Course Title	Approximate Date of Purchase

You can help ensure that distance learning courseware is of top quality by letting us know of areas that need to be adjusted. Call the Alberta Distance Learning Centre free of charge by using the RITE line and ask for the Editing Unit. Also, a Teacher Questionnaire has been included at the back of the Learning Facilitator's Manual. Please take a moment to fill this out.

We look forward to hearing from you!

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Chemistry Data Booklet

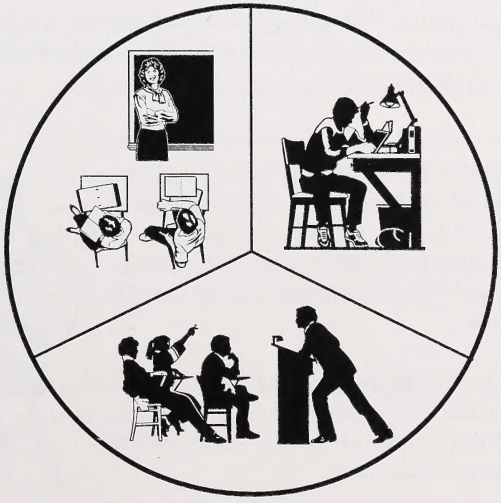
Teacher Questionnaire

Introduction

A survey of these course materials will confirm that this new learning package has been specially designed for many kinds of teachers working in a variety of situations.

Which Category Do You Fit?

- ❑ Small Schools Teacher
  - ❑ inexperienced
  - ❑ experienced, but in other subject areas
  - ❑ experienced in teaching Chemistry 30, but wanting to try a different approach
- ❑ Distance Learning Teacher
  - ❑ travelling to schools within the jurisdiction
  - ❑ using facsimile and teleconferences to teach students within the area
- ❑ Larger Schools Teacher
  - ❑ inexperienced
  - ❑ experienced in teaching Chemistry 30, but wanting to try a different approach



Because these materials have been created by experienced classroom teachers and distance learning specialists, they have many advantages for students and teachers regardless of their situations.

Advantages for Students

- incorporates a strong learner-centred philosophy
- promotes such qualities in the learner as autonomy, independence, and flexibility
- is developed through media which suit the needs and circumstances of the learner
- reflects the experiential background of Alberta students
- opens up opportunities by overcoming barriers that result from geographical location
- promotes individualized learning, allowing learners to work at their own pace

Advantages for Teachers

- allows teachers maximum teaching time and minimizes preparation time
- includes different routes through the materials to suit different learners
- incorporates a wide range of teaching strategies, in particular those using independent and individual learning
- delivers curriculum designed by education specialists that reflects the Alberta Education Program of Studies with an emphasis on Canadian content
- provides learning materials which are upwardly compatible with advanced educational technology

Does it sound like something you could use?

This Learning Facilitator's Manual begins with an overview of the current Alberta Education Program of Studies for Chemistry 30. This summary is included for inexperienced teachers or those teachers who have found themselves teaching Chemistry 30 when their training is in other subject areas. This brief summary is not meant to replace the Alberta Education Program of Studies, but rather to help teachers confirm the highlights of the program.

Other parts of this introduction have also been included to help teachers become familiar with this new learning package and determine how they might want to use it in their classroom.

Beyond the introduction the guide itself contains answers, models, explanations, and other tips generated by the teachers who authored this course.

The module booklets and LFMs are the products of experienced classroom teachers and distance learning specialists. It is the hope of these teachers that their experience can be shared with those who want to take advantage of it.

Overview of the Program of Studies

The Chemistry 20/30 program is one result of Alberta Education's Secondary Education Review of 1985. The policy set forward by this review established new requirements for high school graduation. High school students are now required to complete a minimum of two science courses (eight credits) to obtain a General High School Diploma and three science courses (fifteen credits) to obtain an Advanced High School Diploma. This increased demand for science credits has led to a restructuring of the science programs in Alberta.

The various course sequences in the senior high science program are illustrated in the *Senior High Science Teacher Resource Manual*, 1992, Curriculum Branch, Alberta Education.

Science, Technology, and Society

The 1985 policy statement, *Secondary Education in Alberta*, also directed the new high school science program to emphasize the application of basic scientific concepts and principles in the real world. The new high school science program has achieved this by emphasizing the interrelationship of science, technology, and society (STS). The STS approach is intended to provide students with a more balanced science education, one with an emphasis on science in the real world, rather than focussing on a body of knowledge isolated from its social context.

The teaching of science using the STS approach must centre on the development of scientifically literate and responsible citizens capable of using scientific knowledge wisely. The STS approach to science challenges students by developing scientific literacy through experimentation and investigation. This approach motivates students to learn more about science and to apply what they learn to other situations.

Technology is often the main point of contact individuals have with science. High school students are intrigued by the ever-developing gadgets and processes that characterize this age. There is therefore a tremendous opportunity, when dealing with the relationship between science and technology, to make the subject come alive. Science deals with gravity and friction, but technology gives civilization the wheel. While science asks *why*, technology asks *how*. Science is aimed at increasing human understanding and ability to explain nature. Technology is aimed at developing devices or processes that have practical purposes.

Science and technology affect every aspect of the daily life of Canadians. Both science and technology are involved in areas as diverse as communications, travel, agriculture, and waste management. But what is science and what is technology? Are they the same or are they different? How do science and technology affect society? How does society control science and technology? If students are to become enlightened, contributing citizens in a constantly changing society, they will need to know the answer to these questions.

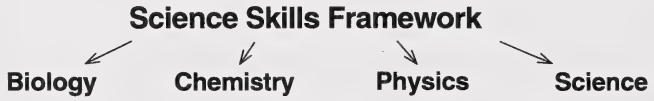
Scientific literacy is an important goal of secondary school education, as it provides a means for asking and answering some very important questions.

A New Chemistry Curriculum

Within the new science program framework, all science courses have several aspects in common:

- There are a common rationale and philosophy, common goals, and general learner expectations.
- Students focus on learning the big interconnecting ideas and principles.
- There is an increased emphasis on developing methods of inquiry that characterize the study of science.
- The students gain an appreciation for the roles of science and technology in understanding nature and the environment, as well as the societal implications of science and technology.
- The context for learning is made relevant to the students by providing concrete experiences that students can relate to their world.
- The students are placed at the centre of their own learning which creates a more active learner with increased responsibilities.
- The inquiry process allows students to exercise their creativity and develop critical problem-solving skills through experimentation, problem-solving activities, and independent study.

The Chemistry 20/30 program emphasizes the key science themes: energy, matter, change, systems, diversity, and equilibrium. Chemistry 30 focuses on systems, energy, change, and equilibrium. Within these themes, students can develop an appreciation for chemistry's place in their world, as well as its connections to other science disciplines.



The development of the new science programs has necessitated a review of assessment methods. Since the growth of science problem-solving skills in students is a priority of the science curricula, assessment methods must reflect this emphasis.

The document, *A Model for the Assessment and Evaluation of Scientific Problem-Solving Skills*, Draft, June 8, 1992, has direct implications for ADLC students and school students using distance learning materials. The following proposal attempts to incorporate the evaluation scheme into distance learning materials.

There are six categories in which the science skills of students will be assessed:

A. Initiating and Planning
B. Collecting and Recording
C. Organizing and Communicating
D. Analysing
E. Connecting, Synthesizing, and Integrating
F. Evaluating the Process or Outcome

Each category will be assessed according to a level scheme as discussed in the document. This scheme will need to be explained to students. Each course will have a standard explanation outlining the assessment model in Module 1.

Each course will have a science skills spreadsheet that allows students to record their progress in completing the science skills component of selected assignment questions throughout the course. The Chemistry 30 spreadsheet is in the appendix of Module 1. Science skills could be evaluated in the context of a lab investigation, a research project, a case study, or a group project. The framework for scientific problem-solving skills is explained in the Appendix of Module 1.

Each course will have to ensure that students have opportunities to be evaluated in each of the skills. In addition, students will need to be given formative practice at developing the skills throughout the activities and investigations. **Note:** The skill level indicated by the teacher to the student in the assignment questions is **NOT** reflected in the mark of the questions.

The evaluation of these skills will be ongoing throughout each science course. Students will be encouraged to do self-evaluation as well as a summative evaluation that focuses on growth and improvement.

Self-Evaluation

- When students do the activities in their module booklets, the science skills icon will reinforce which skills are being practiced. Students will be encouraged to reflect on their skill level.

- When students complete a question in the assignment that focuses on a science skill, they will be asked to evaluate the level of their response before it is submitted for grading. The teacher marking the assignment will then supply the student with his or her evaluation of the response along with a concise explanation if the level is different from what the student suggested.

- This area of self-evaluation will be explored further and enhanced for the 30-level courses.

- Self-evaluation concludes by students analysing their own progress as displayed on the spreadsheet. A mark will be given for this spreadsheet upon its completion. Each time their assignments are returned, the students are expected to transfer both the teacher level assessment and their own level assessment to the spreadsheet.

Summative Evaluation

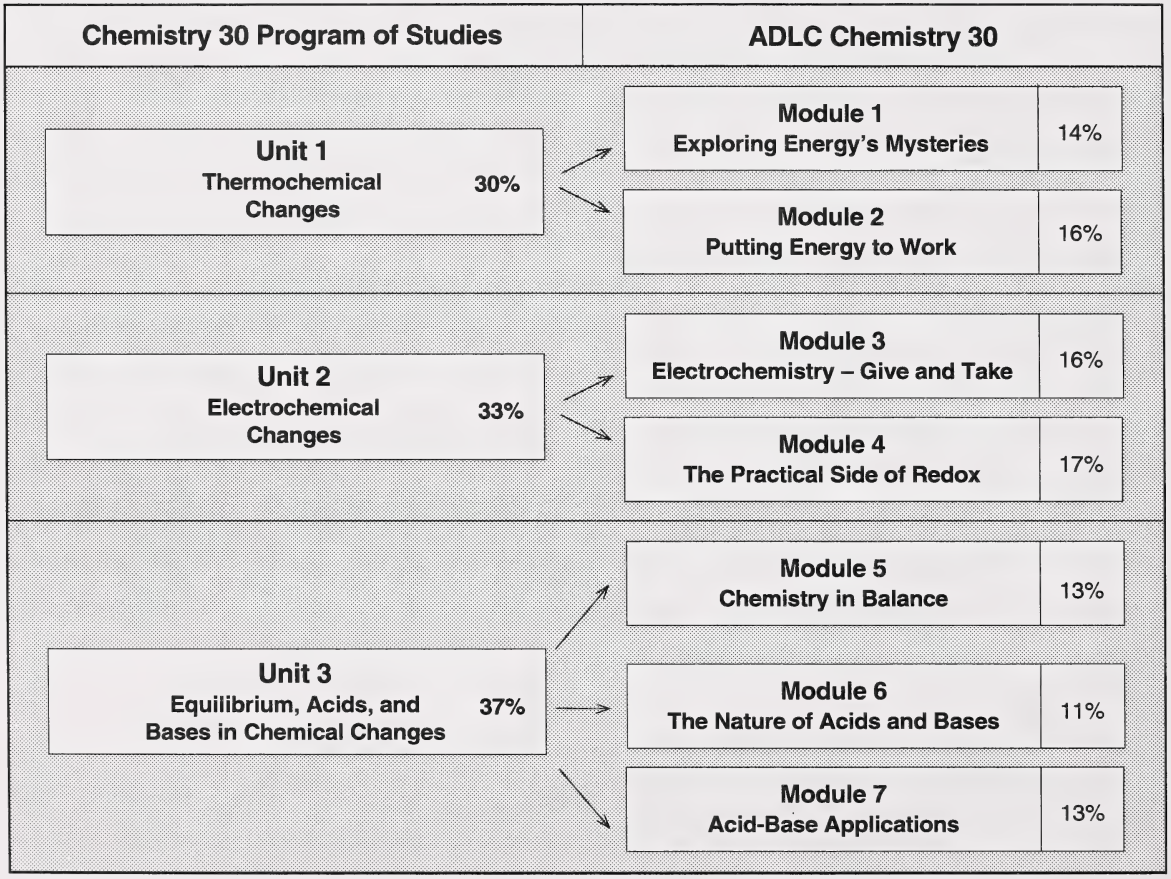
- The level of a student's performance will be determined by the teacher throughout the course. As shown in Self-Evaluation, the level of performance for a particular science skill or set of skills will be assessed in the assignment questions that have been "flagged."

- The students will carefully track their progress throughout the course by recording their level and the teacher's level of assessment of achievement on their spreadsheet. The teacher will keep an on-going record of all teacher level assessment.

Overview of Chemistry 30

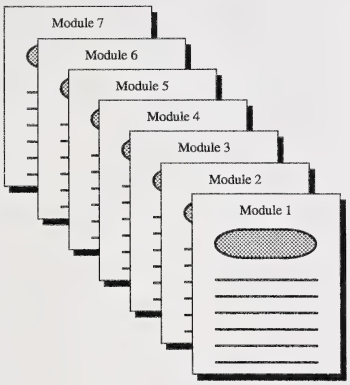
The ADLC Chemistry 30 course is made up of seven modules. Modules 1 and 2 deal with energy changes in systems. Modules 3 and 4 focus on electrochemistry and its practical applications. Module 5 deals with various aspects of chemical equilibrium. Modules 6 and 7 then apply equilibrium principles to concepts centred around acids and bases.

The sequence of modules follows the Chemistry 30 program of studies as outlined by the Curriculum Branch, Department of Education. The following graphic illustrates the relationship between the program of studies and the Chemistry 30 program as produced by the Alberta Distance Learning Centre. The recommended percentages of available instructional time are based on work compiled by a committee for Alberta Education, Student Evaluation Branch.



Structure of the Learning Package

Module Booklets



The print components involve many booklets called modules. These modules contain guided activities that instruct students in a relevant, realistic setting, as well as assignments that can be used for formative and summative assessments.

The modules have been specially designed to promote such qualities in the learner as autonomy, independence, and flexibility. Writers have incorporated such teaching strategies as working from the concrete to the abstract, linking the old to the new, getting students actively involved, and using advance, intermediate, and post organizers. Many other techniques enable learners to learn on their own for at least some of the time.

Contents
Overview Evaluation
Section 1 Activity 1 Activity 2 etc. Assignment
Section 2 Activity 1 Activity 2 etc. Assignment
Section 3 Activity 1 Activity 2 etc. Assignment
Section 4 Activity 1 Activity 2 etc. Assignment
Module Summary

The structure of the module booklets follows a systematic design. Each module begins with a detailed table of contents which shows the students all the main steps. It acts as an organizer for students. The overview introduces the module topic or theme. A graphic representation has been included to help visual learners and poor readers. The introduction also states the weightings of each assignment and provides instruction for setting up the response pages that are submitted to the teacher.

The body of the module is made up of two or more closely related sections. Each section contains student activities that develop skills and knowledge centred around a theme.

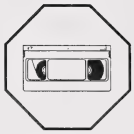
The activities may involve print, audio, video, computer, or laser videodisc formats. At times the student and the learning facilitator are allowed to choose the activity that best suits the student's needs and interests. Other activities such as the Extra Help and Enrichment are optional pathways. This flexibility caters to each student's personal situation.

The summary focuses on the skills and strategies that the student has learned.

The students should complete each section assignment after they have thoroughly reviewed the section. Some modules also have a final module assignment after the Module Summary.

Media

The package also includes references to media. There are activities that require students to view certain videos. These mandatory videos are listed on the following page. It is important that you acquire these videos as you are planning the course. In addition to the mandatory videos, optional videos have been mentioned at various points in the modules. A list of the optional videos is also included on the following page. More information about the videos can be found within the LFM. If you are interested in using laser videodiscs as additional resources, it is recommended that you acquire the *Nelson Chemistry Teacher's Edition*. This binder includes laser videodisc bar codes that match the textbook concepts to the laser videodisc series *Cosmic Chemistry*.

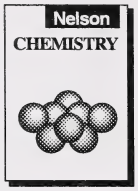


VIDEOCASSETTE

LASER VIDEODISC

Textbooks and Reference Books

The package requires students to use *Nelson Chemistry* as their textbook. Additional reference materials are indicated later in this manual.

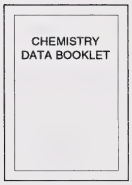


Lab and Other Materials

The package includes references to lab materials. A list of necessary materials is included later in this manual. Also, a list of materials to be supplied by the students is included in the Appendix of Module 7.

Chemistry Data Booklet

A chemistry data booklet is included in the Appendix of Module 7 and in the LFM final test.



Materials, Media, and Equipment

Mandatory Components

Equipment (Hardware)	Media	Materials
• VCR	• Mandatory Video List: (*Chemistry 30 Video*) – *How Safe Is Enough?* – *Electrochemistry Series* – The Building Blocks of Electrochemistry – Electrochemical Cells – Designing Electrochemical Cells – Electroplating – *Chemical Equilibrium Series* – Dynamic Equilibrium – Equilibrium Constant – Reaction Tendencies – The Haber Process – *Planet Under Pressure Series* – Acid Assault	• LFM for Chemistry 30 • one complete set of module booklets (7) • There is a final test.

Videocassettes or laser videodiscs used in the course may be available from the Learning Resources Distributing Centre or ACCESS Network. You may also wish to call your regional library service for more information.

Optional Components

Equipment (Hardware)	Media	Materials
• VCR • laser videodisc player	• laser videodiscs – *Chemistry at Work* – *The Chemistry Disc: Exothermic and Endothermic Reactions* – *Cosmic Chemistry* • Optional Video List: – *Chemical Energy* (Classroom Video) – *Redox* (Classroom Video) – *Electrochemical Cells* (CHEM Study – Ward's) – *Chemical Equilibrium* (Classroom Video) – *Acid-Base Indicators* (CHEM Study – Ward's)	

Using This Learning Package in the Classroom

Conventional Classroom

Whether your classroom has desks in rows or tables in small groups, you may be most comfortable with a learning system that you can use with all your students in a paced style. In other words, you may want a package that will suit all of your students, so they can move through the materials as one group or several small groups. Because these materials contain different routes or pathways within each module, they can address various learning styles and preferences. The materials also include many choices within the activities to cater to different thinking levels and ability levels. Because of their versatility and flexibility, these materials can easily suit a conventional classroom.

Open-Learning Classroom

Open learning is the concept of opening up opportunities by overcoming barriers of time, pace, and place by giving the learners a package specially designed to enable them to learn on their own for at least some of the time.

Such a concept is not new. Many teachers can recite attempts to establish an individualized learning system as they recognized the importance of trying to personalize courseware to meet each individual student's needs. But these efforts often failed due to lack of time and lack of quality materials that conformed to Alberta specifications.

Due to advanced educational technology and improved Alberta-specific learning packages, a student-centred approach is now possible. Improved technology now allows us to provide support to learners individually, regardless of their pace or location. A teacher cannot be in twenty-eight places at one time offering guidance. However, media and a well-designed learning package can satisfy individual needs. Technology can also help provide an effective management system needed to track the students as they progress independently through the materials.

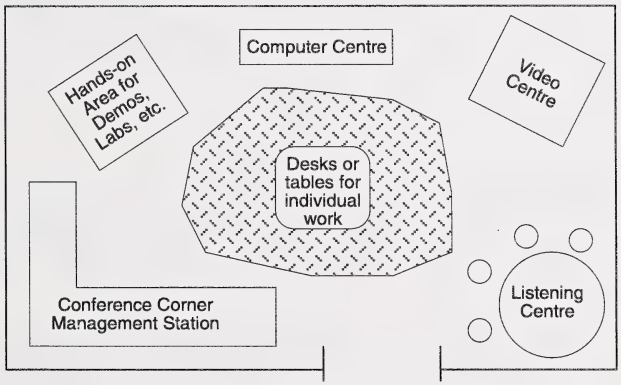
The key to a successful open-learning system depends on three vital elements: a learning package specially designed to enable students to learn effectively on their own for at least some of the time; various kinds of learner support; and a management system and style that ensures that the open-learning system runs smoothly.

The Key to a Successful Open-Learning System

Learning Package

The specially designed learning package needed for a successful open-learning system has been developed for you. The objectives teach current Alberta specifications using strategies designed for individualized instruction. As the learning facilitator, you need to be sure to have all the components in the learning package available to students as needed.

If adequate numbers of media are available to satisfy the demand, a centre can be established for specific media.



You may not have the luxury to have enough hardware to set up a permanent video or computer centre in your classroom. In that case, students should be encouraged to plan ahead. Perhaps every three to five days they should preview their materials and project when they would need a certain piece of media. This would allow you to group students, if necessary, or reserve media as required.

Support

Support is definitely a key element for successful learning, and when you're planning an individualized, non-paced program, you need to carefully plan when and how support will be given.

The materials contain a form of consistent support by providing immediate feedback for activities included in the module booklet. High school students have solutions, models, explanations, and guides included in the appendix of every module booklet. These are included so students can receive immediate feedback to clarify and reinforce their basic understanding before they move on to higher levels of thinking.

As the learning facilitator, you may be needed to offer more personal guidance to those students having difficulty, or you may need to reinforce the need for students to do these activities carefully before attempting the section assignments.

The activities include choices and pathways. If a student is having difficulty, you may need to encourage that student to work on all the choices rather than one. This would provide additional instruction and practice in a variety of ways.

Another form of support is routine contact with each individual. This might be achieved with a biweekly conference scheduled by you, or as students reach a certain point (e.g., after each section is completed), they may be directed to come to the conference area.

Special counselling may be needed to help students through difficult stages. Praise and encouragement are important motivators, particularly for those students who are not used to working independently.

Direct teaching may be needed and scheduled at certain points in the program. This might involve small groups or a large group. It might be used to take advantage of something timely (e.g., election, eclipse, etc.), something prescheduled like the demonstration of a process, or something involving students in a hands-on, practical experience.

Support at a distance might include tutoring by phone, teleconferencing, faxing, or planned visits. These contacts are the lifeline between learners and distance education teachers, so a warm dialogue is essential.

Management

Good management of an open-learning system is essential to the success of the program. The following areas need action to ensure that the system runs smoothly:

- Scheduling, Distributing, and Managing Resources – As discussed earlier, this may require a need for centres or a system for students to project and reserve the necessary resources.

- Scheduling Students – Students and teachers should work together to establish goals, course completion timelines, and daily timelines. Although students may push to continue for long periods of time (e.g., all morning), teachers should discourage this. Concentration, retention, and motivation are improved by taking scheduled breaks.

- Monitoring Student Progress – You will need to record when modules are completed by each student. Your data might also include the projected date of completion if you are using a student contract approach.

Sample of a Student Progress Chart

Chemistry 30		Module 1	Module 2	Module 3	Module 4	Module 5	Module 6	Module 7	Final Test
Billy Adams	P								
	A								
Louise Despins	P								
	A								
Violet Klaissian	P								
	A								
P = Projected Completion Date A = Actual Completion Date									

The student could keep a personal log as well. Such tracking of data could be stored easily on a computer.

- Recording Student Assessments – You will need to record the marks awarded to each student for work completed in each section assignment. The marks from these assignments will contribute to a portion of the student's final mark. Other criteria may also be added (a special project, effort, attitude, etc.). Whatever the criteria, they should be made clear to all students at the beginning.

Sample of a Student Assessment Chart

Chemistry 30	Module 1	Module 2	Module 3	Module 4	Module 5	Module 6	Module 7	Year's Average	Final Test	Final Mark
Billy Adams	**67**	**65**	**54**	**47**	**78**	**67**	**63**	**63**		
Louise Despins	**43**	**50**	**54**	**55**	**48**	**42**	**49**	**49**		
Violet Klaissian	**65**	**65**	**66**	**68**	**67**	**70**	**67**	**67**		

Letter grading could easily be substituted.

- Recording Effectiveness of System – Keep ongoing records of how the system is working. This will help you in future planning.

Sample of a System Assessment Chart

Module 1			
Date	Activities	Assignments	Resources/Media

The Role of the Teacher in an Open-Learning Classroom

The teachers in a conventional classroom spend a lot of time talking to large groups of learners. The situation in open learning requires a different emphasis. Teachers will probably meet learners individually or in very small groups.

With this approach it is necessary to move beyond the idea of a passive learner depending largely on a continually supportive teacher. The teacher must aim to build the student's confidence, to stimulate the learner into self-reliance, and to guide the learner to take advantage of routes that are most meaningful and applicable to the learner.

These materials are student-centred, not teacher-centred. The teacher needs to facilitate learning by providing general support to the learner.

Evaluation

Evaluation is important to the development of every learner. Data gathering and processing, and decision making, at the student and teacher level, serve as means of identifying strengths and weaknesses.

These specially designed learning packages contain many kinds of informal and formal evaluation.

Observation

In the classroom the teacher has the opportunity to see each student perform every day and to become aware of the level and nature of each student's performance.

Observations are more useful if they are recorded in an organized system. The following list of questions is a sample of types of observations and how they can be collected.

Observation Checklist

	B. Adams	L. Despins	V. Klaissian	H. Smith	K. Dalley
1. Does the student approach the work in a positive manner?					
2. Is the student struggling with the reading level?					
3. Does the student make good use of time?					
4. Does the student apply an appropriate study method?					
5. Can the student use references effectively, etc.?					

Observation may suggest a need for an individual interview with a student.

Individual Conferences

Individual conferences may be paced (scheduled) by the calendar, at certain points in the module, or they may be set up only as needed or requested.

During these conferences teachers can determine the student's progress and can assess the student's attitudes toward the subject, the program, school, and self, as well as the student's relationship with other students. With guided questions the teacher can encourage oral self-assessment; the student can discuss personal strengths or weaknesses in regard to the particular section, module, or subject area.

Self-Appraisal

Self-appraisal helps students recognize their own strengths and weaknesses. Through activities that require self-assessment, students also gain immediate feedback and clarification at early stages in the learning process. Teachers need to promote a responsible attitude toward these self-assessment activities. Becoming effective self-assessors is a crucial part of becoming autonomous learners. By instructing, motivating, providing positive reinforcement, and systematically supervising, the learning facilitator will help students develop a positive attitude toward their own progress.

For variation, students may be paired and peer-assessing may become part of the system. The teacher may decide to have the student self-assess some of the activities, have a peer assess other activities, and become directly involved in assessing the remainder of the activities.

When the activities have been assessed, the student should be directed to make corrections. This should be made clear to students right from the start. It is important to note the correct association between the question and the response to clarify understanding, aid retention, and be of use for study purposes.

Many of the activities include choices for the student. If the student is having difficulty, more practice may be warranted, and the student may need to be encouraged to do more of the choices.

Each section within a module includes additional types of activities called Extra Help and Enrichment. Students are expected to be involved in the decision as to which pathway best suits their needs. They may decide to do both.

Self-appraisal techniques can also be introduced at the individual conferences. Such questions as the following might be included:

- What steps are you taking to improve your understanding of this topic?
- What method of study do you use most?
- How do you organize your material to remember it?
- What steps do you follow when doing an assignment?
- What could you do to become an even better reader?
- Do you have trouble following directions?
- Did you enjoy this module?

A chart or checklist could be used for recording responses.

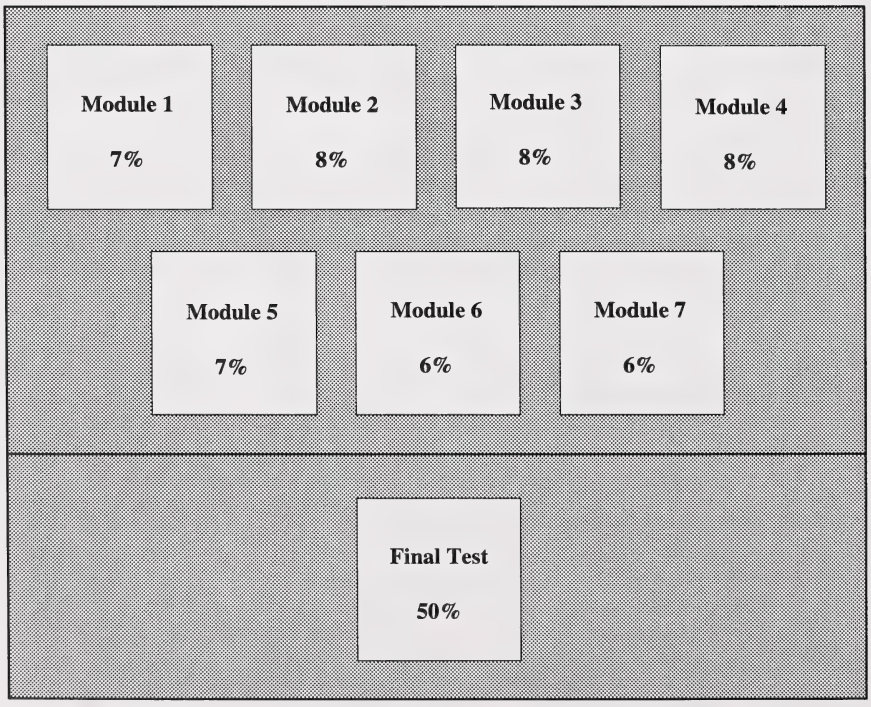
Informal Evaluation: Assignments

Informal evaluation, such as the assignments included in each module, are an invaluable aid to the teacher. They offer ongoing assessment information about the student's achievement and the behaviour and attitudes that affect that achievement.

Each module contains a number of assignments. These assignments assess the knowledge or skills that the student has gained from the module. **The student's mark for the module may be based solely on the outcome of learning evident in the assignments; however, you may decide to establish a value for other variables such as attitude or effort.** It is important that you establish at the beginning which outcomes will be evaluated, and that all students clearly understand what is expected.

Final Test

All LFMs include a formal final test which can be photocopied for each member of the class. The test, closely linked to the learning outcomes stated in the module booklets, gives the teacher precise information concerning what each student can or cannot do. Answers, explanations, and marking guides are also included. The final test is structured in a similar fashion to the Chemistry 30 diploma exam which also must be written by the students. The value of the final test and each module is the decision of the classroom teacher. Following is a suggestion only.



Introducing Students to the System

Your initiation to these learning materials began with a basic survey of what was included and how the components varied. This same process should be used with the class. After the materials have been explored, a discussion might include the advantages and the disadvantages of learning independently or in small groups. The roles of the students and teacher should be analysed. The necessary progress checks and rules need to be addressed. Your introduction should motivate students and build a responsible attitude toward learning autonomously.

Skill Level

It is important for students to understand that there are certain skills that they will need in order to deal successfully with the course materials. They are listed below:

- understanding and using instructional materials (table of contents, index, list of illustrations, WHMIS labels associated with lab materials, appendices, bibliography, and glossary)
- interpreting lab data, graphs, and charts
- using reference materials
- utilizing science skills
- using a scientific calculator
- communicating in a precise and effective manner

Other general skills are using reliable study methods, outlining, and learning to read at a flexible rate.

To decide the level and amount of instruction needed to accommodate the varied levels among students, you may wish to prepare and administer skill inventories or pretests. If most students need help with a particular skill, you may want to plan a total class instructional session. If only certain students lack a skill, you may want to set up a temporary skill group to help students who need it, or you may want to develop a skills file for this purpose.

Reading Level

These course materials are largely print based, but poorer readers need not be discouraged. It is important that you assure the students that these materials have been designed for easy reading. The authors have employed special strategies that lower and control the reading level. Some of them are

- the conscious selection of vocabulary and careful structuring of sentences to keep the materials at an independent reading level
- the integration of activities, examples, and illustrations to break text into appropriate-sized chunks
- the inclusion of many kinds of organizers (advance, graphic, intermediate, concept mapping, post organizers) to help give students a structure for incorporating new concepts

- the recognition that vocabulary and concepts are basic to understanding content materials and, thus, must be handled systematically (defined in context, marginal notes, footnotes, and often in a specialized glossary)

- the acknowledgement that background knowledge and experience play a vital role in comprehension

- the systematic inclusion of illustrations and videos to help poorer readers and visual learners, and audiocassettes and software as an alternative to print-based learning

- a variety of formats (paragraphs, lists, charts, etc.) to help poorer readers who do not absorb or retain main ideas easily in paragraph format

- the inclusion of media and activity choices to encourage an active rather than passive approach

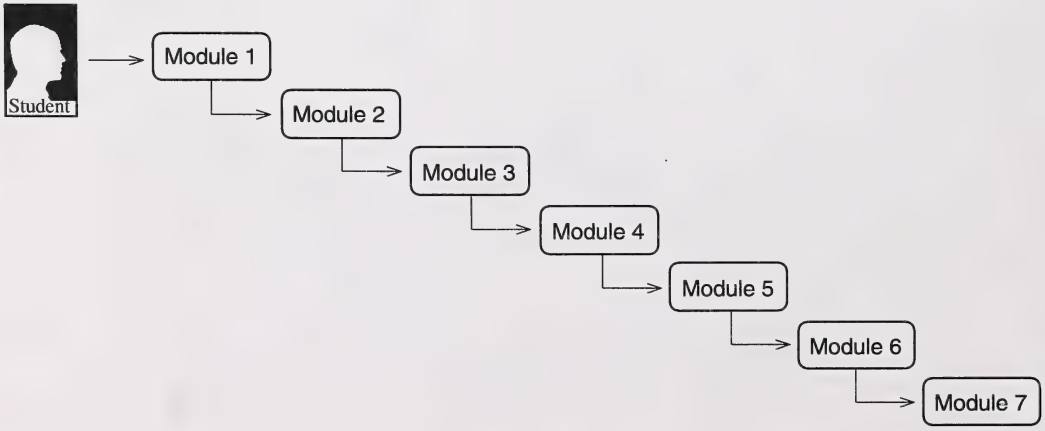
- instruction in a meaningful setting rather than in a contrived, workbook style

- using purposeful reading, viewing, and doing to produce better interpretation of the course materials

- the recognition that students need structured experiences when reading, viewing, or listening to instructional materials: developing pupil readiness, determining the purpose, providing guided instruction and feedback, rereading if necessary, and extending (This structure closely resembles the reading process.)

To help make the learning package more readable, you can begin your module preparation by reading (viewing, listening to) all the related materials that are going to be used. You need a solid background in order to assess and develop a background knowledge for students. The students' experiential bases may be assessed through brainstorming sessions concerning the topic, or by using visuals and guided questions to predict what the topic might be about.

It is recommended that you start with Module 1 because this module includes basic introductory information, and it is also recommended that you end with Module 7 because this module acts as a summary or culmination.



Module 1: Exploring Energy's Mysteries

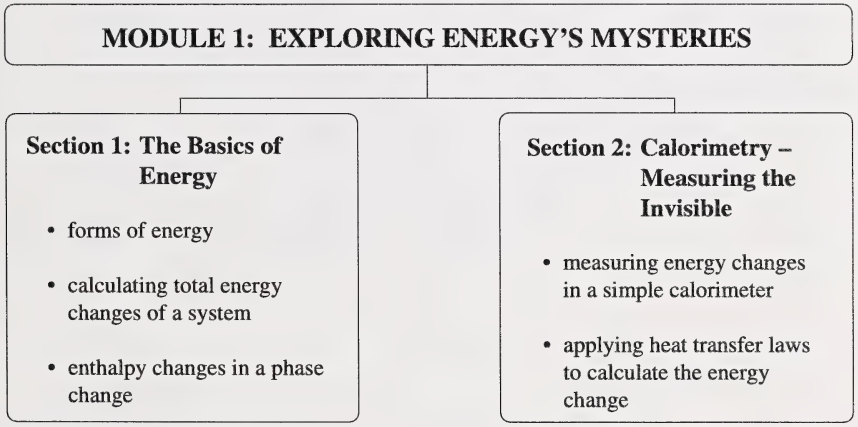
Overview

The emphasis in this module is on energy and systems. Quantitative energy changes involved in physical, chemical, and nuclear thermochemical systems are studied. The major concept of energy changes associated with changes in matter is emphasized. Students are encouraged to develop process skills by doing problems which require them to initiate and plan a design, collect and record data to solve a problem, analyse the data collected, and evaluate their designs. Several STS examples have been used to enhance the application of the major concept and the sub-concepts taught.

Section 1 provides the framework for science skills assessment and lays the basic groundwork for energy in systems by describing the concepts of heat transfer, enthalpy, and the total energy of a system. Section 2 then applies the basic concepts to a detailed study of calorimetry, culminating in a comparative study to energy changes in biological and mechanical systems.

The Appendix contains charts outlining the expectations at various levels in science skills assessment. A sample spreadsheet for recording results follows these charts. The chart may be photocopied or reproduced as required. It is to be handed in by students with the final assignment in Module 7.

The Appendix also contains valuable information for students to prepare them for the Chemistry 30 Diploma Examination. This information goes along with the further information on diploma examinations discussed in the final module.


MODULE 1: EXPLORING ENERGY'S MYSTERIES
Section 1: The Basics of Energy
• forms of energy
• calculating total energy changes of a system
• enthalpy changes in a phase change
Section 2: Calorimetry – Measuring the Invisible
• measuring energy changes in a simple calorimeter
• applying heat transfer laws to calculate the energy change

Evaluation

The evaluation of this module will be based on two section assignments and one module assignment:

Section 1 Assignment	**35 marks**
Section 2 Assignment	**40 marks**
Final Module Assignment	**25 marks**
TOTAL	**100 marks**

Materials and Equipment

The following is a list of materials necessary for completing the investigations and activities in Module 1. Amounts stated represent requirements per student.

Section 1: Activity 1

Investigation 1.1: Stain Removal

See page 19 of *Nelson Chemistry* for a list of materials.

Investigation: Aluminum in Copper(II) Chloride

- 10 cm × 10 cm piece of aluminum foil
- 250 mL beaker
- 5 g copper(II) chloride dihydrate
- stirring rod
- 75 mL distilled water
- thermometer

Section 1: Activity 2

Investigation 10.1: Designing and Evaluating a Water Heater

- 2 tin cans, one large (1.4 L juice) and one small (280 mL soup)
- mineral wool or fibreglass insulation
- thermometer
- hot plate
- 100 mL graduated cylinder
- oven mitts
- a circular piece of polystyrene (preferable) or cardboard (to use as a lid for the heater)
- 100 mL water
- can-opener or nails (to make vent holes)

The heater used to collect the observations is shown in the Appendix, Section 1: Activity 1 of the student module booklet.

It is important that any flammable insulating materials are not used. It is recommended that a slow heating process is used, preferably with a hot plate. Mineral wool or calcium silicate as insulation seems to be the safest. Mineral wool is cheap and should be available in a local insulation shop. Pre-formed calcium silicate is available commercially at insulation shops as well. It is heavier and more expensive. Both these materials are resistant up to 500°C when exposed to flame.

Section 1: Enrichment (optional)

Investigation: Measuring the Specific Heat Capacity of Water

- a kettle of known power output
- balance
- stop watch
- thermometer

Section 2: Activity 2

Investigation 10.2: Molar Enthalpy of Solution

- 5.35 g solid ammonium chloride/trial
- balance
- thermometer
- scoop
- 100 mL graduated cylinder
- 2 polystyrene cups with a lid to fit
- 250 mL beaker (for support)
- safety equipment

Other chemicals which can be used are potassium nitrate and ammonium nitrate. These both create endothermic changes and can be used as a demonstration at the same time. If sodium hydroxide is used to give an exothermic change, students must be informed about the hazards of solid sodium hydroxide touching the skin.

Section 2: Activity 3

Investigation 10.3: Molar Enthalpy of Reaction

- 50 mL of 1.0 mol/L $NaOH_{(aq)}$/trial
- 2 medicine droppers
- (2) 250 mL beakers
- wash bottle
- 50 mL of 1.0 mol/L $H_2SO_{4(aq)}$/trial
- simple calorimeter apparatus
- 50 mL graduated cylinder
- lab safety equipment

Students should be cautioned about working with a strong acid and how to clean acid spills.

Investigation 10.4: Designing a Calorimeter for Combustion Reactions

- metal can calorimeter
  - small tin can (280 mL can – one end removed)
  - large tin can (1.4 L juice can – both ends removed)
  - aluminum foil
  - fibreglass insulation or mineral wool
  - clothes hanger wire
  - cardboard or polystyrene for lid
- paraffin candle
- 100 mL graduated cylinder
- thermometer
- jam jar lids
- can-opener or tin snips
- matches
- balance

The same calorimeter as used in Investigation 10.1 can be used. Once again the students should be cautioned about the use of flammable insulation.

Section 2: Enrichment (optional)

Investigation: Determining the Heat of Combustion of a Peanut

- 1 pop can
- thermometer
- matches
- elastic bands
- peanuts (unsalted)
- 1 cork
- oven mitts
- ring stand
- piece of cardboard
- 3 paper clips
- water

Final Module Assignment

Investigation: Specific Heat Capacity of Canola Oil

- balance
- polystyrene calorimeter
- 15 g to 20 g oil (cooking canola oil)
- graduated cylinder or measuring cup
- 100 mL water
- heating source
- string
- 500 mL beaker or cooking pan for water bath
- thermometer
- 2 plastic freezer bags (small)

Teaching Tip: Students can be asked to compare the specific heat capacities of different oils.

Additional Resources

Brady, J.E., and G.E. Humiston. 1986. *General Chemistry: Principles and Structure*. Toronto: John Wiley and Sons, Inc.

Whitman, R.L., E.E. Zinck, and R.A. Nalepa. 1988. *Chemistry Today*. 3d Ed. Scarborough, Ont.: Prentice-Hall Canada Inc.

Snyder, C.H. 1992. *The Extraordinary Chemistry of Ordinary Things*. Toronto: John Wiley & Sons, Inc.

Possible Media

Laser Videodiscs

Cosmic Chemistry. (1992) Optical Data Corporation, New Jersey.

Note: Some of the suggested media may not be authorized by Alberta Education. Teachers should use their own discretion regarding the use of these resources in their classroom.

Section 1: The Basics of Energy

Key Concepts

The objective of this section is to introduce the students to the terminology associated with thermochemistry. The section distinguishes between the words *forms*, *types*, and *sources of energy*. This is followed by introducing the terms *phase change* and *chemical change*. Energy changes of endothermic and exothermic natures are related to each type of system. The relationships $q = mc\Delta t$ (used to quantify heat flow) and $\Delta H = nH$ (used to quantify enthalpy change) are introduced. Students solve simple problems involving these relationships.

Teaching Suggestions

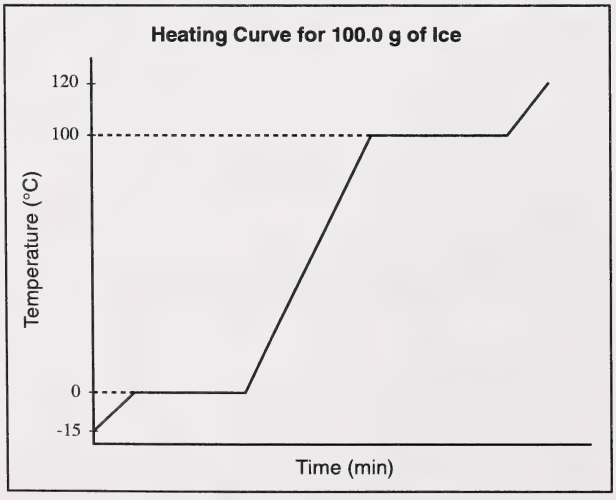
- It may be important to explain to students that *Nelson Chemistry*'s use of the symbol H with a subscript to denote a molar enthalpy change is not universal. Most resources, including the diploma examination data booklet, use the symbol ΔH with subscripts for all enthalpy values given. *Nelson Chemistry* has used this notation to try and simplify the distinction between molar enthalpy values and other enthalpy changes.
- The topic on phase changes can be introduced by posing a problem such as, How can freezing be used industrially to purify salt water?
- Debate on which is the most efficient fuel and most economical fuel.
- If your classroom has a calendar, use a picture in the calendar and ask the students to find out the different forms of energy depicted in the picture. You may also use various photographs from magazines.

Note: A chemistry data booklet is included in the Appendix of Module 7. This booklet is almost identical to the one that students will use when writing the Chemistry 30 diploma examination. You have the option of having your students use this booklet as their source of data, or having them use the textbook data pages. A black and white chemistry data booklet is also included in the LFM final test.

If you wish your students to use the full-colour version of the data booklet for their final in-class test, you may have to order the booklets from Alberta Education, Student Evaluation Branch.

Section 1: Assignment Answer Key (35 marks)

1. a.



(3 marks)

b. There are five energy changes contributing to the total energy change of the water.

$$\Delta E_{total} = \underset{\begin{pmatrix}\text{solid}\\ \text{warming}\end{pmatrix}}{q} + \underset{(\text{melting})}{\Delta H_{fus}} + \underset{\begin{pmatrix}\text{liquid}\\ \text{warming}\end{pmatrix}}{q} + \underset{(\text{vaporization})}{\Delta H_{vap}} + \underset{\begin{pmatrix}\text{steam}\\ \text{warming}\end{pmatrix}}{q}$$

$$= mc\Delta t + nH_{fus} + mc\Delta t + nH_{vap} + mc\Delta t$$

$$= 0.100\ \text{kg} \times \frac{2.01\ \text{kJ}}{\text{kg} \bullet ^\circ\text{C}} \times (0 - (-15.0))^\circ\text{C} + 100\ \text{g} \times \frac{1\ \text{mol}}{18.02\ \text{g}} \times \frac{6.03\ \text{kJ}}{\text{mol}} + 0.100\ \text{kg} \times \frac{4.19\ \text{kJ}}{\text{kg} \bullet ^\circ\text{C}} \times (100.0 - 0)^\circ\text{C}$$

$$+ 100\ \text{g} \times \frac{1\ \text{mol}}{18.02\ \text{g}} \times \frac{40.8\ \text{kJ}}{\text{mol}} + 0.100\ \text{kg} \times \frac{2.01\ \text{kJ}}{\text{kg} \bullet ^\circ\text{C}} \times (120 - 100)^\circ\text{C}$$

$= 309\ \text{kJ}$ The total energy change is 309 kJ. **(6 marks)**

2. The final temperature (t_f) will equal the initial temperature (t_i) plus the temperature change (Δt).

$$q = mc\Delta t$$

$$20.0\ \text{kJ} = 0.700\ \text{kg} \times \frac{4.19\ \text{kJ}}{\text{kg} \bullet ^\circ\text{C}} \times \Delta t$$

$$\Delta t = \frac{20.0\ \text{kJ}}{0.700\ \text{kg} \times 4.19\ \text{kJ/kg} \bullet ^\circ\text{C}}$$

$$= 6.82^\circ\text{C}$$

$$\text{final temperature } (t_f) = t_i + \Delta t$$

$$t_f = 25.0^\circ\text{C} + 6.82^\circ\text{C}$$

$$= 31.8^\circ\text{C}$$

The final temperature is 31.8°C. **(4 marks)**

3. Heat is a form of energy transferred between substances. Temperature is a measure of the average kinetic energy of a substance. Following are two examples to illustrate the difference between heat and temperature.

- Heat flowing into a system that is not at a point of phase change results in molecules moving faster. This increases the average kinetic energy of the system and therefore the temperature.

  The same amount of heat transferred into a system at the point of a phase change would now be absorbed as potential energy to change the state of the system. At this point the temperature would not change.

- Using the two given beakers as a different example, the same amount of heat energy added to each beaker will not create the same temperature change. Temperature not only depends on the amount of heat energy but also on the amount of substance and the type of substance. The beaker with the smaller mass of water will increase the most in temperature.

100 mL beaker

$$q = mc\Delta t$$

$$10\ \text{kJ} = 0.100\ \text{kg} \times \frac{4.19\ \text{kJ}}{\text{kg} \bullet ^\circ\text{C}} \times \Delta t$$

$$\Delta t = \frac{10\ \text{kJ}}{0.100\ \text{kg} \times 4.19\ \text{kJ/kg} \bullet ^\circ\text{C}}$$

$$= 24^\circ\text{C}$$

250 mL beaker

$$q = mc\Delta t$$

$$10\ \text{kJ} = 0.250\ \text{kg} \times \frac{4.19\ \text{kJ}}{\text{kg} \bullet ^\circ\text{C}} \times \Delta t$$

$$\Delta t = \frac{10\ \text{kJ}}{0.250\ \text{kg} \times 4.19\ \text{kJ/kg} \bullet ^\circ\text{C}}$$

$$= 9.5^\circ\text{C}$$

same heat $\rightarrow$ different temperatures **(6 marks)**

4. $\Delta H_{vap} = nH_{vap}$

$$= 2.00\ \text{g} \times \frac{1\ \text{mol}}{22.99\ \text{g}} \times \frac{101\ \text{kJ}}{1\ \text{mol}}$$

$$= 8.79\ \text{kJ}$$

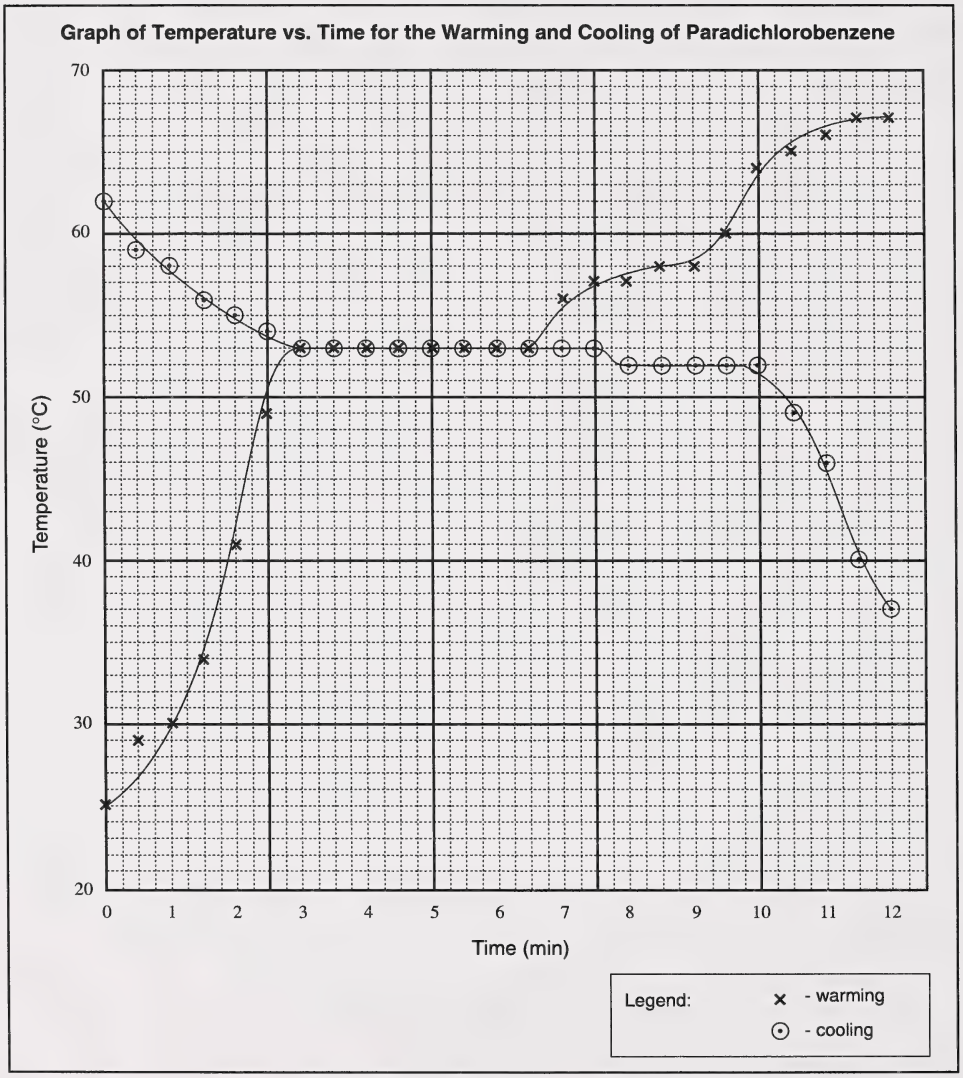
The enthalpy change for the sodium is 8.79 kJ. **(3 marks)**

5. a. Muffins baking in an oven involve heat energy changing to chemical energy. **(1 mark)**

   b. Hearing someone talking to you on the phone involves electrical energy changing to sound energy. **(1 mark)**

   c. A person diving into a pool involves potential energy changing to kinetic energy or chemical energy changing to mechanical energy. **(1 mark)**

6. a.



(4 marks)

   b. The manipulated variable is time and the responding variable is temperature. **(2 marks)**

   c. The melting point and the freezing point is 53.0°C. **(2 marks)**

d. The plateaus of the curves will be longer as it will take longer time to melt or freeze the compound. The slopes of the curves will be more gradual. **(1 mark)**

e. The temperature does not change because the incoming or outgoing energy is used to break or make bonds between molecules as a potential energy change – the kinetic energy does not change. **(1 mark)**

Section 2: Calorimetry – Measuring the Invisible

Key Concepts

The emphasis of this section is on measuring energy changes in a lab. The principle of conservation of energy is introduced. This is then applied to an isolated system like a calorimeter. The description of a regular calorimeter, a simple polystyrene calorimeter and a bomb calorimeter is given. The relationship $\Delta E_{loss} = \Delta E_{gain}$ is explained and the students are then asked to solve problems which require them to determine the molar heats of solution, phase changes, and chemical changes.

Teaching Suggestions

You can use the molar heat of solution of ammonium nitrate as a demonstration to make students familiar with the use of a simple calorimeter. Students should be asked to record the highest or lowest temperature reached in each investigation.

Section 2: Assignment Answer Key (40 marks)

1. $\Delta H = q$

(cake) (water)

$\Delta H = 1000 \text{ kJ}$

$1000 \text{ kJ} = mc\Delta t$

$$1000 \text{ kJ} = m \times \frac{4.19 \text{ kJ}}{\text{kg} \bullet ^\circ\text{C}} \times (37.0 - 2.0)^\circ\text{C}$$

$$m = \frac{1000 \text{ kJ}}{147 \text{ kJ/kg}}$$

$= 6.8 \text{ kg or } 6.8 \text{ L}$ The amount of water required is 6.8 kg or 6.8 L. **(4 marks)**

2. a.

$$\Delta H_l = \Delta H_g$$

(silver) (calorimeter)

$$\Delta H_s + q = q$$

(silver solidifying) (silver cooling) (calorimeter water warming)

$$nH_s + mc\Delta t = mc\Delta t$$

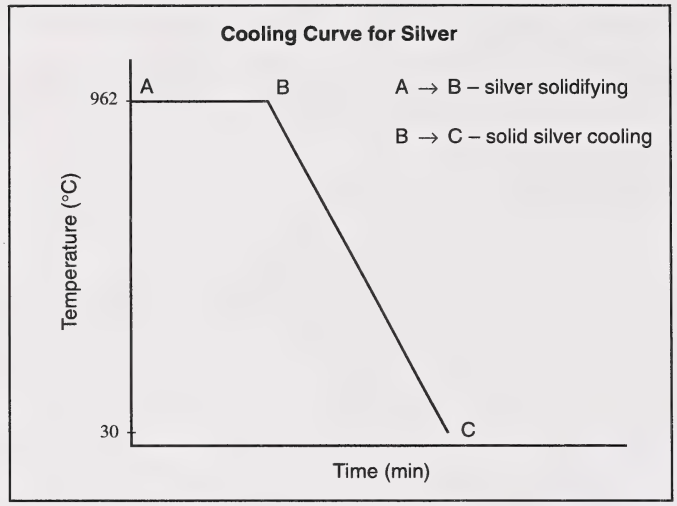
$$\left(45.0 \text{ g} \times \frac{1 \text{ mol}}{107.87 \text{ g}} \times H_s\right) + \left(0.0450 \text{ kg} \times \frac{0.235 \text{ kJ}}{\text{kg} \bullet ^\circ\text{C}} \times (962 - 30.0)^\circ\text{C}\right) = 0.750 \text{ kg} \times \frac{4.19 \text{ kJ}}{\text{kg} \bullet ^\circ\text{C}} \times (30.0 - 25.0)^\circ\text{C}$$

$$H_s = \frac{5.8566 \text{ kJ}}{0.417 \text{ mol}}$$

$$= 14.0 \text{ kJ/mol}$$

The molar heat of solidification for silver is –14.0 kJ/mol. **(5 marks)**

b.



(4 marks)

3. a.

$$q_{(\text{iron})} = q_{(\text{water})}$$

$$mc\Delta t = mc\Delta t$$

$$0.100\ \text{kg} \times \frac{0.444\ \text{kJ}}{\text{kg} \bullet ^\circ\text{C}} \times (300 - t_f)^\circ\text{C} = 0.250\ \text{kg} \times \frac{4.19\ \text{kJ}}{\text{kg} \bullet ^\circ\text{C}} \times (t_f - 25.0)^\circ\text{C}$$

$$13.3\ \text{kJ} - 0.0444 \frac{\text{kJ}}{^\circ\text{C}}(t_f) = 1.05 \frac{\text{kJ}}{^\circ\text{C}}(t_f) - 26.2\ \text{kJ}$$

$$39.5\ \text{kJ} = 1.09 \frac{\text{kJ}}{^\circ\text{C}}(t_f)$$

$$t_f = \frac{39.5\ \text{kJ}}{1.09\ \text{kJ/°C}}$$

$$= 36.2^\circ\text{C}$$

The final temperature of the iron + water system is 36.2°C. **(4 marks)**

b. Each metal has a different specific heat capacity. Therefore a given quantity of energy will cause a different temperature change for each system. **(1 mark)**

c. The aluminum pot would keep water warmer longest since it has the largest specific heat capacity and therefore the greatest amount of energy to release. **(2 marks)**

4. a.

$$\Delta H_{c\,(\text{ethanol})} = q_{(\text{water})}$$

$$nH_c = mc\Delta t$$

$$(127.67 - 124.47)\text{g} \times \frac{1\ \text{mol}}{46.08\ \text{g}} \times H_c = 0.250\ \text{kg} \times \frac{4.19\ \text{kJ}}{\text{kg} \bullet ^\circ\text{C}} \times (90.0 - 20.0)^\circ\text{C}$$

$$H_c = \frac{73.3\ \text{kJ}}{0.0694\ \text{mol}}$$

$$= 1.06 \times 10^3\ \text{kJ/mol}\ (1.06\ \text{MJ/mol})$$

The molar heat of combustion for ethanol is –1.06 MJ/mol. **(4 marks)**

b. $$\%\ \text{error} = \frac{|\text{experimental value} - \text{accepted value}|}{|\text{accepted value}|} \times 100\%$$

$$= \frac{|-1056-(-1235)|}{|-1235|} \times 100\%$$

$$= 14.5\%$$ The student's percent error is 14.5%.

The experimental error is high, indicating that more trials are required to obtain a more reliable result or that the experimental design may have to be revised. **(2 marks)**

5. a. Ethanol has stronger intermolecular bonds because it takes longer (30 s longer) to break these bonds when changing from a liquid to a gaseous state. This indicates that more heat energy must be added to ethanol than to hexane. **(2 marks)**

b. $$\text{Rate of heating for ethanol} = 2.75\ \text{kJ} \times \frac{1}{50\ \text{s}}$$

$$= 0.055\ \frac{\text{kJ}}{\text{s}}$$

$$\text{Energy required for hexane} = 20\ \text{s} \times \frac{0.055\ \text{kJ}}{\text{s}}$$

$$= 1.1\ \text{kJ}$$

1.1 kJ would be required to vaporize hexane. **(3 marks)**

c. $$H_{vap} = 2.75\ \text{kJ} \times \frac{1}{3.0\ \text{g}} \times \frac{46.08\ \text{g}}{1\ \text{mol}}$$

$$= 42\ \frac{\text{kJ}}{\text{mol}}$$

The molar heat of vaporization for ethanol is +42 kJ/mol. **(3 marks)**

6. a. The two assumptions would be as follows:

- There is no loss of heat energy when the titanium is transferred to the calorimeter.
- There is no loss of heat from the calorimeter water to the surroundings. **(2 marks)**

b. $$q_{(\text{titanium})} = q_{(\text{water})}$$

$$mc\Delta t = mc\Delta t$$

$$72.6\ \text{g} \times c \times (98.2-29.4)^\circ\text{C} = 100.0\ \text{g} \times \frac{4.19\ \text{J}}{\text{g}\bullet^\circ\text{C}} \times (29.4-23.5)^\circ\text{C}$$

$$c = \frac{2472\ \text{J}}{4995\ \text{g}\bullet^\circ\text{C}}$$

$$= 0.495\ \text{J/g}\bullet^\circ\text{C}$$

The specific heat capacity of titanium is $0.495\ \text{J/g}\bullet^\circ\text{C}$. **(4 marks)**

Final Module Assignment Answer Key (25 marks)

Part A: Multiple Choice

1. D 2. C 3. D 4. A 5. B **(5 marks)**

Part B: Written Response

1. The investigation report should be similar to the following.

a. **Materials**

- balance
- polystyrene calorimeter
- oil (cooking canola oil)
- graduated cylinder (or measuring cup)
- string or twist tie
- thermometer
- 2 plastic sandwich or freezer bags (small)
- water
- heating source
- 500 mL beaker or cooking pan for water bath **(2 marks)**

b. **Procedure**

- Measure and record the mass of the oil plus its container.
- Remove 15-20 g of oil into a small plastic bag and remass the container and oil.
- Prepare a 60-65°C water bath by heating about 400 mL of water in a beaker or cooking pan.
- Place the plastic bag with oil inside another plastic bag. The inner bag can be tied shut if desired.
- Carefully place the plastic bag with oil in the warm water bath.
- Cool about 150 mL of water to between 5°C and 10°C.
- Measure 100.0 mL of the cool water into a polystyrene calorimeter.
- Measure and record the initial temperature of the calorimeter water.
- Place the thermometer inside the oil bag and tie the bag.
- Measure and record the initial temperature of the oil, once it has reached the temperature of the surrounding warm water bath.
- Quickly transfer the plastic bag with the oil and thermometer from the warm water bath to the calorimeter.
- Place the lid on the calorimeter and record the lowest temperature reached by the oil (the final temperature).
- Repeat the procedure twice to obtain consistent results. **(4 marks)**

c. **Evidence Table**

Data	Trial 1	Trial 2	Trial 3
initial mass of container + oil (g)	71.2	61.3	65.7
final mass of container + oil (g)	49.7	40.5	45.0
mass of calorimeter water (g)	100.0	100.0	100.0
initial temperature of oil (°C)	57.4	56.8	61.9
initial temperature of calorimeter water (°C)	10.0	7.0	9.0
final temperature of entire system (°C)	15.0	12.3	14.5

(2 marks)

d. **Analysis**

Calculations	Trial 1	Trial 2	Trial 3
mass of canola oil (g)	71.2 − 49.7 = 21.5	61.3 − 40.5 = 20.8	65.7 − 45.0 = 20.7
temperature change of the oil (°C)	57.4 − 15.0 = 42.4	56.8 − 12.3 = 44.5	61.9 − 14.5 = 47.4
temperature change of the water (°C)	15.0 − 10.0 = 5.0	12.3 − 7.0 = 5.3	14.5 − 9.0 = 5.5

Trial 1 Calculation:

$$q_{(\text{oil})} = q_{(\text{calorimeter})}$$

$$mc\Delta t = mc\Delta t$$

$$0.0215\ \text{kg} \times c \times (71.2 - 49.7)^\circ\text{C} = 0.1000\ \text{kg} \times \frac{4.19\ \text{kJ}}{\text{kg} \bullet {}^\circ\text{C}} \times (15.0 - 10.0)^\circ\text{C}$$

$$c = \frac{2.095\ \text{kJ}}{0.9116\ \text{kg} \bullet {}^\circ\text{C}}$$

$$= 2.30\ \text{kJ/kg} \bullet {}^\circ\text{C}$$

The specific heat for the oil is $2.30\ \text{kJ/kg} \bullet {}^\circ\text{C}$.

The c value for Trial 2 is $2.4\ \text{kJ/kg} \bullet {}^\circ\text{C}$.
The c value for Trial 3 is $2.4\ \text{kJ/kg} \bullet {}^\circ\text{C}$.

$$\text{average } c \text{ value} = \frac{(2.30 + 2.4 + 2.4)\ \text{kJ/kg} \bullet {}^\circ\text{C}}{3}$$

$$= 2.4\ \text{kJ/kg} \bullet {}^\circ\text{C}$$

Note: The analysis calculation could have been performed by first averaging the mass and temperature values, then performing one specific heat capacity calculation. **(4 marks)**

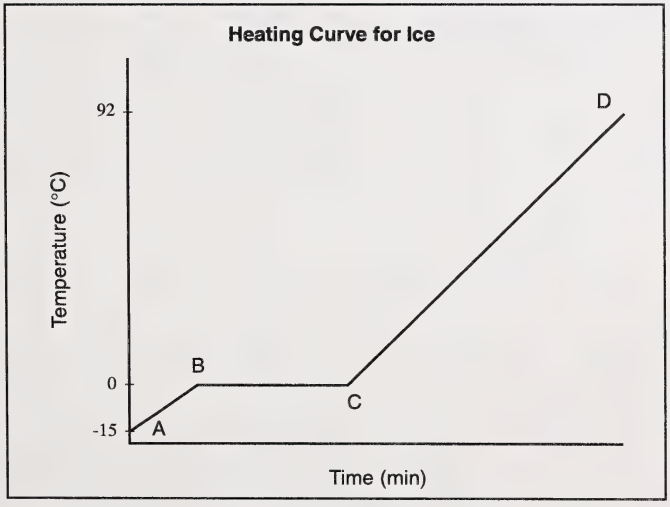
e. The assumptions made are as follows:

- Minimal heat is lost to the calorimeter or surroundings from the calorimeter water.
- Minimal heat is lost to the surroundings when the oil is transferred. **(1 mark)**

f. The sources of error are the following:

- Heat may be lost to the surroundings during the transfer of oil to the calorimeter.
- The oil sample may not be pure canola oil.
- Some of the oil may spread on the inner surface of the plastic bag and not come into contact with the calorimeter water.
- Some heat energy may be absorbed by the plastic bag. **(2 marks)**

2.



A → B – ice warming
B → C – ice melting
C → D – water warming

(3 marks)

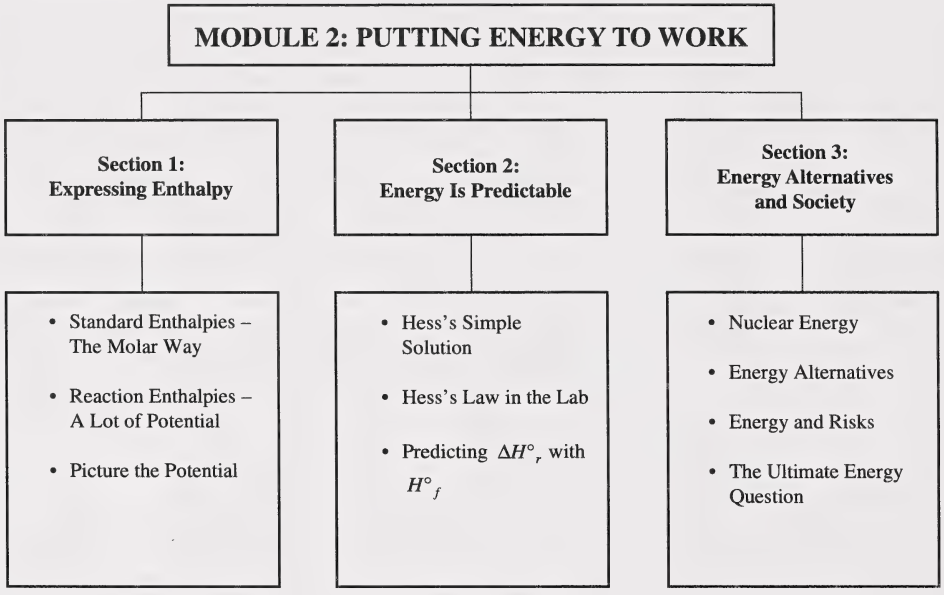
3. Lead ($c = 0.159\ \text{J/g} \bullet {}^\circ\text{C}$) will have a greater increase in temperature than copper ($c = 0.385\ \text{J/g} \bullet {}^\circ\text{C}$) because it has a lower specific heat capacity. **(2 marks)**

Module 2: Putting Energy to Work

Overview

Emphasis in this module is on expressing enthalpy changes. Students also focus on some alternative forms of fuels. However, determining and communicating enthalpy changes for chemical changes is explored in detail.

A possible way to introduce this module is to relate enthalpy change to cellular respiration. Background information should be given explaining that the main blood sugar in humans is glucose. To give you energy, glucose is very slowly burned by the oxygen you inhale, so that the body temperature does not increase. The question posed to the students is – How can you determine the enthalpy change for this reaction in a chemistry laboratory? A short discussion of possible methods can follow. These methods can be related to studying enthalpy changes for other chemical changes as well.


MODULE 2: PUTTING ENERGY TO WORK
Section 1: Expressing Enthalpy
Section 2: Energy Is Predictable
Section 3: Energy Alternatives and Society
• Standard Enthalpies – The Molar Way
• Reaction Enthalpies – A Lot of Potential
• Picture the Potential
• Hess's Simple Solution
• Hess's Law in the Lab
• Predicting $\Delta H°_r$ with $H°_f$
• Nuclear Energy
• Energy Alternatives
• Energy and Risks
• The Ultimate Energy Question

Evaluation

The evaluation of this module will be based on three section assignments and one module assignment:

Section 1 Assignment	**30 marks**
Section 2 Assignment	**30 marks**
Section 3 Assignment	**15 marks**
Final Module Assignment	**25 marks**
TOTAL	**100 marks**

Materials and Equipment

The following is a list of materials necessary for completing the investigations and activities in Module 2. Amounts stated represent requirements per student.

Section 2: Activity 2

Investigation 11.1: Applying Hess's Law

A complete list of materials for this investigation can be found on page 326 of *Nelson Chemistry*, with the addition of the following:

- thermometer

Additional Resources

_____. *Chemistry Matters Magazine*. Robson, David P., ed. Columbus, OH: American Chemical Society.

Golob, Richard, and Eric Brus, ed. 1990. *The Almanac of Science and Technology*. Boston: World of Information Systems, Harcourt Brace Jovanovich, Inc.

Wilbraham, Anthony, D.D. Staley, et. al. 1993. *Addison-Wesley Chemistry*. 3d ed. Don Mills, Ontario: Addison-Wesley Publishing Company, Inc.

Other

Alberta Energy Research and Technology Branch. Government of Alberta.

Possible Media

Video

Chemical Energy. (1992) Classroom Video, Vancouver, B.C.

How Safe Is Enough? (1983) Atomic Energy of Canada Limited, Ottawa.

Petroleum: River of Energy. (1989) (ACCESS Network)

Laser Videodiscs

Cosmic Chemistry. (1992) Optical Data Corporation, New Jersey.

Section 1: Expressing Enthalpy

Key Concepts

In this section the students will learn four methods of communicating enthalpies of chemical changes. The terms *heat of reaction*, *molar heat of reaction*, and *molar enthalpy of reaction* will be introduced. Students will be introduced to the concept of writing thermochemical equations and interpreting them. Drawing and interpreting potential energy diagrams for enthalpy changes during chemical changes will be discussed. This is followed by problem solving using each of the four methods discussed.

Teaching Suggestions

- The teacher should stress the difference between molar enthalpy and total enthalpy change. One way is to relate the terms to molar mass which is the mass for one mole rather than the total mass of a substance in a reaction.
- Emphasize the significance of potential energy diagrams; enough practice should be given to plot them using the correct energy values on the vertical axis as well. Students in general have difficulty plotting the energy values on the *y*-axis. This difficulty can be overcome by solving a problem and then plotting a graph in class – using the values from your problem and plotting them on the potential energy diagram.
- Also emphasize that *Nelson Chemistry* uses its own form of notation for molar enthalpy (H_r) which is not used by most other references (ΔH_r). Distance Learning chemistry materials will follow the textbook so as not to confuse the students.

Section 1: Assignment Answer Key (30 marks)

1. a. The enthalpy change for 1.00 kg of methane is calculated as follows:

$$\Delta H_r = nH_r$$

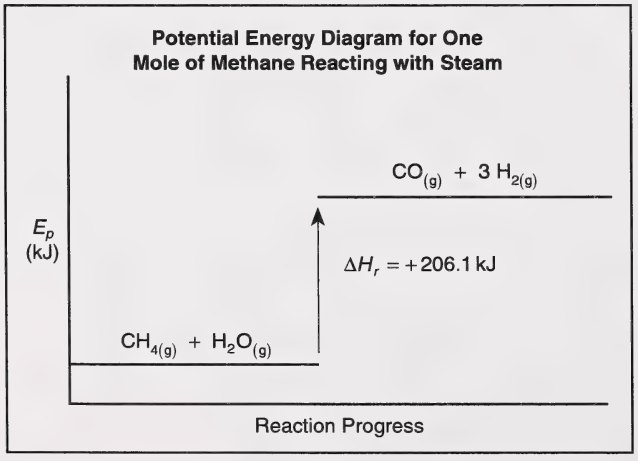
$$\Delta H_r = 1.00\ \cancel{\text{kg}} \times \frac{1000\ \cancel{\text{g}}}{1\ \cancel{\text{kg}}} \times \frac{1\ \cancel{\text{mol}}}{16.05\ \cancel{\text{g}}} \times \frac{+206.1\ \text{kJ}}{\cancel{\text{mol}}}$$

$$= +1.28 \times 10^4\ \text{kJ}\ (+12.8\ \text{MJ})$$ The enthalpy change is +12.8 MJ. **(4 marks)**

b. $206.1\ \text{kJ} + CH_{4(g)} + H_2O_{(g)} \rightarrow CO_{(g)} + 3\ H_{2(g)}$ **(1 mark)**

Reverse reaction: $CO_{(g)} + 3\ H_{2(g)} \rightarrow CH_{4(g)} + H_2O_{(g)} \quad \Delta H_r = -206.1\ \text{kJ}$ **(1 mark)**

c.


Potential Energy Diagram for One Mole of Methane Reacting with Steam
E_p (kJ)
$CO_{(g)} + 3\ H_{2(g)}$
$\Delta H_r = +206.1$ kJ
$CH_{4(g)} + H_2O_{(g)}$
Reaction Progress

(3 marks)

2. Substance X is more stable because it requires more energy to break its lattice structure. The answer can also be explained as follows:

$$X + \text{lattice energy}_1 \rightarrow X\ \text{ions}$$

$$Y + \text{lattice energy}_2 \rightarrow Y\ \text{ions}$$

$$\text{lattice energy}_1 > \text{lattice energy}_2$$

Therefore, when X is formed, more energy is released. The substance X would have less stored energy and would most likely be more stable. **(2 marks)**

3. a. $H_c = \dfrac{-22.6 \text{ kJ}}{1.00 \cancel{\text{g}}} \times \dfrac{32.05 \cancel{\text{g}}}{1 \text{ mol}}$

$= -724 \text{ kJ/mol}$

The molar enthalpy for the combustion of methanol is -724 kJ/mol.

$H_c = \dfrac{-29.7 \text{ kJ}}{1.00 \cancel{\text{g}}} \times \dfrac{46.08 \cancel{\text{g}}}{1 \text{ mol}}$

$= -1369 \text{ kJ/mol}$

$= -1.37 \times 10^3 \text{ kJ/mol} \ (-1.37 \text{ MJ/mol})$

The molar enthalpy for the combustion of ethanol is -1.37×10^3 kJ/mol.

$H_c = \dfrac{-33.4 \text{ kJ}}{1.00 \cancel{\text{g}}} \times \dfrac{60.11 \cancel{\text{g}}}{1 \text{ mol}}$

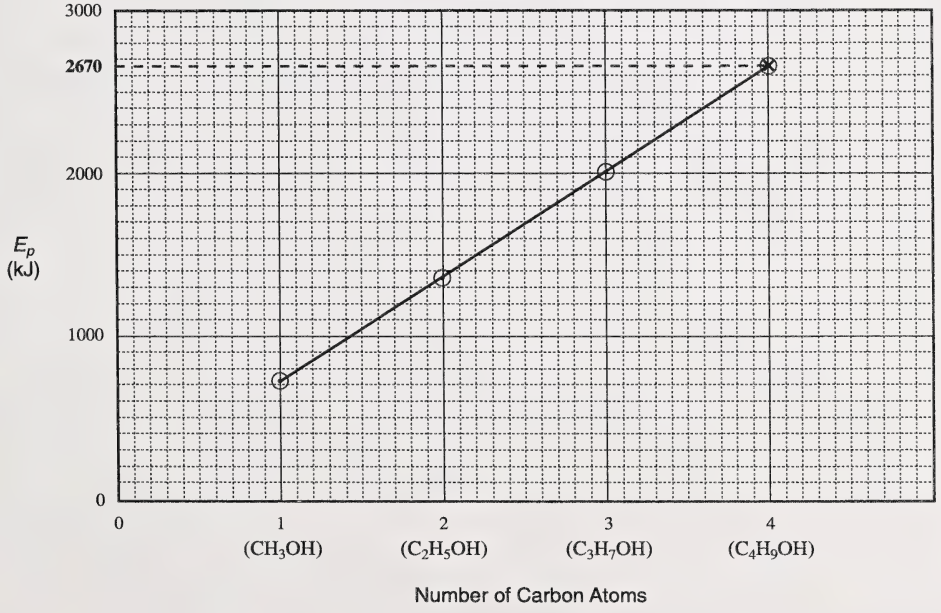
$= -2008 \text{ kJ/mol}$

$= -2.01 \times 10^3 \text{ kJ/mol} \ (-2.01 \text{ MJ/mol})$

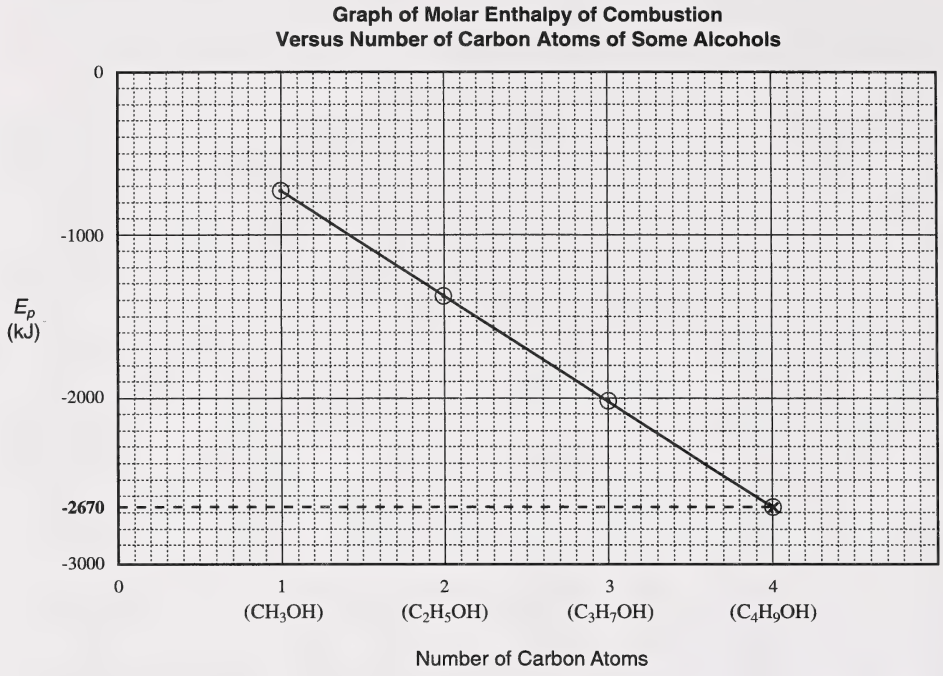
The molar enthalpy for the combustion of propanol is -2.01×10^3 kJ/mol. **(6 marks)**

b. If students choose to plot positive values, their graph should appear as follows:

Graph of Molar Enthalpy of Combustion Versus Number of Carbon Atoms of Some Alcohols



If students choose to use negative signs on their graphed values, their graph should appear as follows:



The estimated molar enthalpy of combustion for butanol from the graph is -2.67×10^3 kJ/mol. (**Note:** An error margin of ±50 kJ/mol should be given.) **(4 marks)**

4. a. endothermic b. endothermic c. exothermic d. exothermic **(4 marks)**

5. The molar enthalpy of combustion for paraffin is calculated as follows.

$$\Delta E_{loss} = \Delta E_{gain}$$
$$\Delta H_c = q$$
$$\text{(paraffin)} \quad \text{(water)}$$
$$nH_c = mc\Delta t$$
$$(25.7-23.5)\text{g}\times\frac{1\text{ mol}}{352.77\text{ g}}\times H_c = 0.3940\text{ kg}\times\frac{4.19\text{ kJ}}{\text{kg}\bullet\text{°C}}\times(35.5-20.0)\text{°C}$$
$$H_c = \frac{25.588\text{ kJ}}{0.006\,2364\text{ mol}}$$
$$= 4.1031\times10^3\text{ kJ/mol}$$
$$= 4.10\times10^3\text{ kJ/mol}$$

The molar enthalpy of combustion for paraffin is -4.10×10^3 kJ/mol. **(5 marks)**

Section 2: Energy Is Predictable

Key Concepts

This section focuses on Hess's law. Two methods are used – rearranging the equations to obtain the net equation and using the relationship $\Delta H = \sum nH^\circ_{fp} - \sum nH^\circ_{fr}$. Students are then introduced to problem solving using these methods. This is followed by a lab investigation in which students are required to apply the calorimetry principles learned previously, along with Hess's law.

Teaching Suggestions

- Introduce the concept of Hess's law by starting with a concrete example to which students can relate. One way is using a net change in position from one place to another even if different routes are used. Another example is travelling by an elevator from one floor to another.
- Students will need to review calorimetry concepts before doing the investigation. They will also need some help to complete the analysis of the investigation. To guide students through the process, the analysis can be broken into different sections. A handout prepared beforehand can be given as a review to the class before the actual day of the investigation.

Section 2: Assignment Answer Key (30 marks)

1. reverse ①: $C_6H_4(OH)_{2(aq)} \rightarrow C_6H_4O_{2(aq)} + \cancel{H_{2(g)}}$ $\quad \Delta H^\circ_r = +177.4$ kJ

   $\frac{1}{2}\times$ ②: $H_2O_{2(aq)} \rightarrow \cancel{\frac{1}{2}O_{2(g)}} + H_2O_{(l)}$ $\quad \Delta H^\circ_r = -94.5$ kJ

   same ③: $\cancel{\frac{1}{2}O_{2(g)}} + \cancel{H_{2(g)}} \rightarrow H_2O_{(l)}$ $\quad \Delta H^\circ_r = -285.8$ kJ

   $C_6H_4(OH)_{2(aq)} + H_2O_{2(aq)} \rightarrow C_6H_4O_{2(aq)} + 2\,H_2O_{(l)}$ $\quad \Delta H^\circ_r = -202.9$ kJ

   The enthalpy change for the reaction is -202.9 kJ. **(4 marks)**

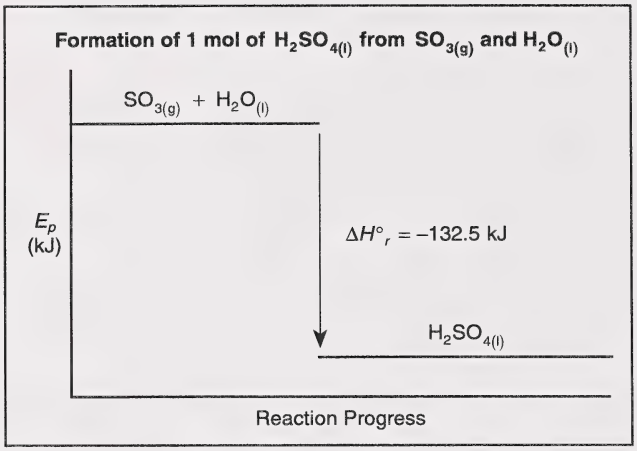
2. a. $SO_{3(g)} + H_2O_{(l)} \rightarrow H_2SO_{4(l)}$

   $1(-395.7)\quad 1(-285.8)\quad 1(-814.0)$

$$\Delta H^\circ_r = \sum nH^\circ_{fp} - \sum nH^\circ_{fr}$$
$$= \left(1\text{ mol} \times \frac{-814\text{ kJ}}{\text{mol}}\right) - \left(1\text{ mol} \times \frac{-395.7\text{ kJ}}{\text{mol}} + 1\text{ mol} \times \frac{-285.8\text{ kJ}}{\text{mol}}\right)$$
$$= -132.5\text{ kJ}$$

The enthalpy change for the reaction is -132.5 kJ. **(4 marks)**

b.



(2 marks)

3.
$$NaCl_{(s)} \rightarrow \cancel{Na^+_{(g)}} + \cancel{Cl^-_{(g)}} \qquad \Delta H_r = +788\,kJ$$
$$\cancel{Na^+_{(g)}} + \cancel{Cl^-_{(g)}} \rightarrow Na^+_{(aq)} + Cl^-_{(aq)} \qquad \Delta H_r = -784\,kJ$$
$$NaCl_{(s)} \rightarrow Na^+_{(aq)} + Cl^-_{(aq)} \qquad \Delta H_{sol} = +4\,kJ$$

The heat of solution for one mole of $NaCl_{(s)}$ is +4 kJ.

(2 marks)

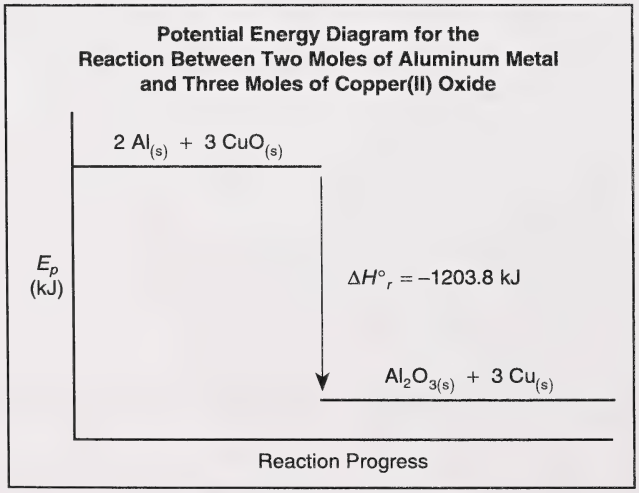
4. a. $2\,Al_{(s)} + 3\,CuO_{(s)} \rightarrow 3\,Cu_{(s)} + Al_2O_{3(s)}$

$2(0) \quad 3(-157.3) \quad 3(0) \quad 1(-1675.7)$

$$\Delta H°_r = \sum nH°_{fp} - \sum nH°_{fr}$$
$$= \left(3\text{ mol} \times \frac{0\text{ kJ}}{\text{mol}} + 1\text{ mol} \times \frac{-1675.7\text{ kJ}}{\text{mol}}\right) - \left(2\text{ mol} \times \frac{0\text{ kJ}}{\text{mol}} + 3\text{ mol} \times \frac{-157.3\text{ kJ}}{\text{mol}}\right)$$
$$= -1203.8\text{ kJ}$$

The enthalpy change for the reaction is −1203.8 kJ. **(4 marks)**

b.


Potential Energy Diagram for the
Reaction Between Two Moles of Aluminum Metal
and Three Moles of Copper(II) Oxide
$2\,Al_{(s)} + 3\,CuO_{(s)}$
E_p (kJ)
$\Delta H°_r = -1203.8$ kJ
$Al_2O_{3(s)} + 3\,Cu_{(s)}$
Reaction Progress

(2 marks)

5. a. The molar enthalpy of reaction for $Ca_{(s)}$ in Reaction ① can be determined as follows:

$$\begin{aligned}
\Delta H_r &= q \\
\begin{pmatrix}\text{Ca}\\ \text{reaction}\end{pmatrix} &\quad \begin{pmatrix}\text{solvent}\\ \text{water}\end{pmatrix} \\
nH_r &= mc\Delta t \\
0.50\text{ g}\times\frac{1\text{ mol}}{40.08\text{ g}}\times H_r &= 0.100\text{ kg}\times\frac{4.19\text{ kJ}}{\text{kg}\bullet^\circ\text{C}}\times(35.9-22.3)^\circ\text{C} \\
H_r &= 456.8\text{ kJ/mol} \\
&= 4.6\times10^2\text{ kJ/mol}
\end{aligned}$$

The molar enthalpy of reaction for $Ca_{(s)}$ is -4.6×10^2 kJ/mol. **(4 marks)**

b. The molar enthalpy of reaction for $CaO_{(s)}$ in Reaction ② can be determined as follows:

$$\begin{aligned}
\Delta H_r &= q \\
\begin{pmatrix}\text{CaO}\\ \text{reaction}\end{pmatrix} &\quad \begin{pmatrix}\text{solvent}\\ \text{water}\end{pmatrix} \\
nH_r &= mc\Delta t \\
1.50\text{ g}\times\frac{1\text{ mol}}{56.08\text{ g}}\times H_r &= 0.100\text{ kg}\times\frac{4.19\text{ kJ}}{\text{kg}\bullet^\circ\text{C}}\times(29.1-22.0)^\circ\text{C} \\
H_r &= 111.22\text{ kJ/mol} \\
&= 111\text{ kJ/mol}
\end{aligned}$$

The molar enthalpy for $CaO_{(s)}$ is -111 kJ/mol. **(4 marks)**

c. Using Hess's law:

same ①:	$Ca_{(s)} + \cancel{2\,HCl_{(aq)}} \rightarrow \cancel{CaCl_{2(aq)}} + \cancel{H_{2(g)}}$	$\Delta H_r = -456.8$ kJ
reverse ②:	$\cancel{CaCl_{2(aq)}} + \cancel{H_2O_{(l)}} \rightarrow CaO_{(s)} + \cancel{2\,HCl_{(aq)}}$	$\Delta H_r = +111.2$ kJ
same ③:	$\cancel{H_{2(g)}} + \frac{1}{2}\,O_{2(g)} \rightarrow \cancel{H_2O_{(l)}}$	$\Delta H_r = -285.8$ kJ
	$Ca_{(s)} + \frac{1}{2}\,O_{2(g)} \rightarrow CaO_{(s)}$	$\Delta H_r = -631.4$ kJ
		$= -6.3\times10^2$ kJ

The enthalpy change for the combustion of calcium metal is -6.3×10^2 kJ. **(4 marks)**

Section 3: Energy Alternatives and Society

Key Concepts

Alternative forms of energy resources is one of the main concepts of this section. The section begins by looking at nuclear changes and compares the relative energy released during nuclear changes to chemical and phase changes. Risks and benefits associated with some alternate fuels are explored.

Teaching Suggestions

- Nuclear changes can be introduced by writing a variety of equations on the board and asking students to classify them as phase, chemical, or nuclear changes. One can then pose the question – Where do nuclear changes occur in nature?
- To introduce the section on risks and benefits, students can be given several situations such as smoking cigarettes, walking alone at night in a city centre, driving automobiles, etc. Then ask students which of the situations they consider risky. The teacher can then expand on the idea of risk. Ask questions such as the following: How did you decide that? What is a risk? Tie in the idea that the same criteria can be applied to using different fuels as an energy source.

Section 3: Assignment Answer Key (15 marks)

1. The molar heat of formation for sodium sulphide can be determined as follows.

$$\begin{array}{rcl} \Delta H_r & = & q \\ \text{(reaction)} & & \text{(water)} \end{array}$$

$$nH_r = mc\Delta t$$

$$11.4\text{ g} \times \frac{1\text{ mol}}{34.08\text{ g}} \times H_r = 0.250\text{ kg} \times \frac{4.19\text{ kJ}}{\text{kg} \bullet ^\circ\text{C}} \times (43.8 - 23.2)^\circ\text{C}$$

$$H_r = \frac{21.579\text{ kJ}}{0.334\,51\text{ mol}}$$

$$= 64.508\text{ kJ/mol}$$

$$= 64.5\text{ kJ/mol} \quad \text{The molar enthalpy is } -64.5\text{ kJ/mol}.$$

$$\Delta H_r = nH_r$$

$$= 1\,\cancel{\text{mol}} \times \frac{-64.508\text{ kJ}}{\cancel{\text{mol}}}$$

$$= -64.508\text{ kJ}$$

$$= -64.5\text{ kJ} \quad \text{The enthalpy change for the reaction is } -64.5\text{ kJ}.$$

$$\begin{array}{lllll} H_2S_{(g)} + & 2\,NaOH_{(s)} & \rightarrow & Na_2S_{(s)} + & 2\,H_2O_{(l)} \qquad \Delta H_r = -64.508\text{ kJ} \\ 1(-20.6) & 2(-425.6) & & (?) & 2(-285.8) \end{array}$$

$$\Delta H^\circ_r = \sum nH^\circ_{fp} - \sum nH^\circ_{fr}$$

$$-64.508\text{ kJ} = \left(1\text{ mol} \times H^\circ_f + 2\text{ mol} \times \frac{-285.8\text{ kJ}}{\text{mol}}\right) - \left(1\text{ mol} \times \frac{-20.6\text{ kJ}}{\text{mol}} + 2\text{ mol} \times \frac{-425.6\text{ kJ}}{\text{mol}}\right)$$

$$-64.508\text{ kJ} = 1\text{ mol} \times H^\circ_f + 300.2\text{ kJ}$$

$$-364.708\text{ kJ} = 1\text{ mol} \times H^\circ_f$$

$$H^\circ_f = \frac{-364.708\text{ kJ}}{1\text{ mol}}$$

$$= -364.7\text{ kJ/mol} \quad \text{The molar heat of formation for } Na_2S_{(s)} \text{ is } -364.7\text{ kJ/mol}. \textbf{ (5 marks)}$$

2. The question can be solved as follows.

$2 \times$ reverse ①: $\quad \cancel{2\,H_2O_{(l)}} \rightarrow \cancel{2\,H_{2(g)}} + \cancel{O_{2(g)}} \qquad \Delta H°_r = +571.6$ kJ

$2 \times$ reverse ②: $\quad \cancel{4\,HNO_{3(l)}} \rightarrow 2\,N_2O_{5(g)} + \cancel{2\,H_2O_{(l)}} \qquad \Delta H°_r = +153.2$ kJ

$4 \times$ ③: $\quad 2\,N_{2(g)} + \cancel{5}\,O_{2(g)} + \cancel{2\,H_{2(g)}} \rightarrow \cancel{4\,HNO_{3(l)}} \qquad \Delta H°_r = -696.4$ kJ

$$2\,N_{2(g)} + 5\,O_{2(g)} \rightarrow 2\,N_2O_{5(g)} \qquad \Delta H°_r = +28.4 \text{ kJ}$$

The $\Delta H°_r$ for the reaction is $+28.4$ kJ. **(4 marks)**

3. a. $^{235}_{92}U$: $H_r = 1.9 \times 10^{10}$ kJ/mol $\qquad$ $^{2}_{1}H$: $H_r = 1.70 \times 10^{9}$ kJ/mol

$$\text{energy/gram} = \frac{1.9 \times 10^{10} \text{ kJ}}{\cancel{\text{mol}}} \times \frac{1 \cancel{\text{mol}}}{235 \text{ g}} = 8.1 \times 10^{7} \text{ kJ/g}$$

$$\text{energy/gram} = \frac{1.70 \times 10^{9} \text{ kJ}}{\cancel{\text{mol}}} \times \frac{1 \cancel{\text{mol}}}{2.0 \text{ g}} = 8.5 \times 10^{8} \text{ kJ/g}$$

$^{2}_{1}H$ is more energy-efficient because it releases more energy per gram than $^{235}_{92}U$. **(3 marks)**

b. The following is one possible answer if Opinion A is chosen.

Fission reactors would be better to use than fusion reactors because

- Controls and safety procedures are well-established and proven for fission reactors.
- The technology for fission reactors is already in place which means less money spent on reactors.
- The mining of uranium ore keeps more workers in jobs than would the production of hydrogen isotopes from water required for the fusion process.

The following is one possible answer if Opinion B is chosen.

Fusion reactors would be better to use than fission reactors because

- Fusion reactors would produce few harmful or toxic materials to pollute the environment as do fission reactors.
- Fusion reactors would use a readily renewable resource; fission reactors will eventually run out of their uranium fuel.
- Fusion reactors would be more energy-efficient, producing more energy per gram of fuel than fission reactors.
- Fusion reactors would be safer because the reaction will only proceed if all conditions are satisfied. They will not go out of control. **(3 marks)**

Final Module Assignment Answer Key (25 marks)

Multiple Choice

1. C 2. D 3. B 4. A 5. C **(5 marks)**

Numerical Response

6. | 3 | 5 | 7 | 9 | **(1 mark)**

7. | 1 | . | 7 | 6 | **(1 mark)**

8. | 4 | 9 | . | 3 | **(1 mark)**

9. | 6 | . | 4 | 2 | **(1 mark)**

10. | 2 | 2 | | | **(1 mark)**

11. | 2 | 5 | . | 5 | **(1 mark)**

12. The following is a sample answer.

Experiment I

$$\begin{gathered}\Delta H_r = q \\ \text{(reaction)} \quad \text{(water)} \\ nH_r = mc\Delta t \\ 0.100\text{ g} \times \frac{1\text{ mol}}{200.0\text{ g}} \times H_r = 10.0\text{ kg} \times \frac{4.19\text{ kJ}}{\text{kg} \bullet ^\circ\text{C}} \times 75^\circ\text{C} \\ H_r = 6.3 \times 10^6\text{ kJ/mol}\end{gathered}$$

Experiment II

$$\begin{gathered}\Delta H_r = q \\ \text{(reaction)} \quad \text{(water)} \\ nH_r = mc\Delta t \\ 1.00\text{ g} \times \frac{1\text{ mol}}{25.0\text{ g}} \times H_r = 0.0100\text{ kg} \times \frac{4.19\text{ kJ}}{\text{kg} \bullet ^\circ\text{C}} \times 85^\circ\text{C} \\ H_r = 89\text{ kJ/mol}\end{gathered}$$

Experiment III

$$\begin{gathered}\Delta H_r = q \\ \text{(reaction)} \quad \text{(water)} \\ nH_r = mc\Delta t \\ 2.00\text{ g} \times \frac{1\text{ mol}}{105.0\text{ g}} \times H_r = 1.00\text{ kg} \times \frac{4.19\text{ kJ}}{\text{kg} \bullet ^\circ\text{C}} \times 45^\circ\text{C} \\ H_r = 9.9 \times 10^3\text{ kJ/mol}\end{gathered}$$

Since $H_{nuclear} > H_{chemical} > H_{phase}$, Experiment I $\left(6.3 \times 10^6\text{ kJ/mol}\right)$ must represent a nuclear change, Experiment III $\left(9.9 \times 10^3\text{ kJ/mol}\right)$ must represent a chemical change, and Experiment II (89 kJ/mol) must represent a phase change. **(8 marks)**

13. The following chart illustrates one way of answering this question.

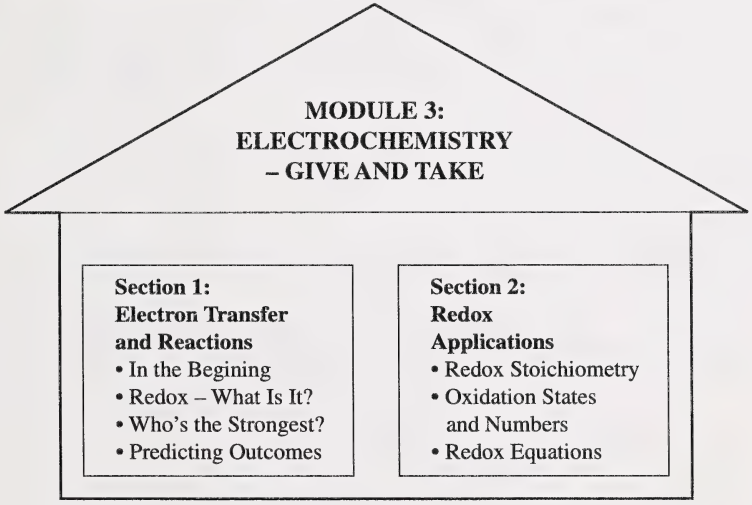
COMPARING RISK ASSESSMENT TO RISK PERCEPTION		
	Risk Assessment	**Risk Perception**
Who does it?	experts	members of the general public
What strategies are used?	statistical analysis	thinking about factors that influence the perception of risk
What is the outcome of this process?	a statistical assessment of risk	a judgement in the mind of the person

(6 marks)

Module 3: Electrochemistry – Give and Take

Overview

There are two main emphases in this module. The first develops the historical background to the terms reduction and oxidation, and moves quickly to the ideas of half-reactions and the loss and gain of electrons that are important to all redox reactions. The first section finishes with the students being able to develop and make use of a redox chart to predict the most likely redox reactions that will take place. Section 2 explores the quantitative aspects of redox by beginning with stoichiometry and moving on to making use of oxidation numbers. The module finishes with the different methods of balancing redox reactions.



Evaluation

The evaluation of this module will be based on two section assignments and one module assignment:

Section 1 Assignment	**40 marks**
Section 2 Assignment	**40 marks**
Final Module Assignment	**20 marks**
TOTAL	**100 marks**

Materials and Equipment

The following is a list of materials necessary for completing the investigations and activities in Module 3. Amounts stated represent requirements per student.

Section 1: Activity 1

Investigation 12.1: Single Replacement Reactions

- 2 mL each of the following 0.10 mol/L solutions
  - silver nitrate
  - copper(II) sulphate
  - hydrochloric acid
  - sodium bromide
  - potassium iodide
- 4 mL aqueous chlorine (chlorine water)
- 5 mL trichlorofluoroethane
- small pieces (about 1 cm in length) of each of the following
  - copper
  - magnesium
  - zinc

- steel wool
- matches
- test tube rack or beaker
- 5 test tubes
- test tube stopper

Note: Make sure the metal strips have been polished clean. There is a diagnostic chart (on page 537 of *Nelson Chemistry)* that the students need to make use of to analyse their data.

Section 1: Activity 2

Investigation 12.2: Spontaneity of Redox Reactions

- 2 mL of 0.10 mol/L solutions of the following
  - copper(II) nitrate
  - lead(II) nitrate
  - silver nitrate
  - zinc nitrate
- 5 small test tubes or spot plate
- waste containers (beakers)
- 0.5 cm-1.0 cm length strips of the following metals
  - copper
  - lead
  - zinc
- steel wool

Note: Make sure the surfaces of the metal strips have been polished clean.

Section 1: Enrichment

Investigation: Colour Changes in Redox Reactions

- galvanized tacks or small nails (available from a hardware store)
- tincture of iodine (available from a drugstore or pharmacy)
- transparent glass or cup
- household bleach
- white vinegar

Section 2: Activity 1

Investigation 12.4: Analysis of a Hydrogen Peroxide Solution

See page 371 in the textbook *Nelson Chemistry* for a complete list of materials.

- 90.0 mL of 0.008 00 mol/L $KMnO_{4(aq)}$
- 2.0 g $FeSO_4 \bullet (NH_4)_2SO_4 \bullet 6H_2O_{(s)}$
- 60.0 mL of 2.0 mol/L $H_2SO_{4(aq)}$
- 40.0 mL of diluted $H_2O_{2(aq)}$

Additional Resources

Brady, James E., and John Holum. 1988. *Fundamentals of Chemistry*. 3d ed. Toronto, Ontario: John Wiley & Sons, Inc.

Possible Media

Videos

Electrochemistry Series. (1986) TV Ontario. (ACCESS Network)
Includes Program 1: Oxidation-Reduction.

World of Chemistry Series. (1988) Annenberg/CPB Project with Raold Hoffmann, Magic Lantern Communications.
Includes a segment on oxidation-reduction.

Redox. (1992) Classroom Video, Vancouver.

Section 1: Electron Transfer and Reactions

Key Concepts

In this section, the student will learn that electrochemical reactions are those that involve a loss and gain of electrons. It is important that the student become familiar with the terms *oxidation, reduction, oxidizing agent, reducing agent,* and *spontaneity*. The student will be introduced to the reduction half-reactions chart and learn how to manipulate its information in predicting the outcome of net overall redox reactions.

Note: Important Correction

The *Redox Half-Reactions* table on page 552 of *Nelson Chemistry* has an error that needs correcting. The dichromate ion half-reaction (eighth from the top) should read as follows:

$$Cr_2O_7^{2-}{}_{(aq)} + 14\ H^+{}_{(aq)} + 6\ e^- \rightleftarrows 2\ Cr^{3+}{}_{(aq)} + 7\ H_2O_{(l)} \qquad \boxed{+1.33}$$

↑ **correction**

The correction means that this (the dichromate) half-reaction should switch positions with the half-reaction above it.

	$Cl_{2(g)} + 2\ e^- \rightleftarrows 2\ Cl^-{}_{(aq)}$	+1.36
new position	$Cr_2O_7^{2-}{}_{(aq)} + 14\ H^+{}_{(aq)} + 6\ e^- \rightleftarrows 2\ Cr^{3+}{}_{(aq)} + 7\ H_2O_{(l)}$	+1.33
	$2\ HNO_{2(aq)} + 4\ H^+{}_{(aq)} + 4\ e^- \rightleftarrows N_2O_{(g)} + 3\ H_2O_{(l)}$	+1.30

Teaching Suggestions

- Although the terms *reduction* and *oxidation* were introduced in Chemistry 20, they should be reviewed.
- The introduction of half-reactions for both oxidation and reduction is important. The terms *oxidizing agent (OA)* and *reducing agent (RA)* and how they each relate to oxidation and reduction need to be solidified in the student's mind.
- It is important to make sure the student understands the terms presented in this section. It is very easy to misunderstand the meaning of each; therefore the use of analogies and mnemonics is helpful.

Section 1: Assignment Answer Key (40 marks)

1. a. OA b. OA/RA c. OA d. RA **(4 marks)**

2. a. The redox table is as follows:

SOA $X^+{}_{(aq)} + 1\ e^- \rightarrow X_{(s)}$

$D^{2+}{}_{(aq)} + 2\ e^- \rightarrow D_{(s)}$

$Z^{2+}{}_{(aq)} + 2\ e^- \rightarrow Z_{(s)}$

$A^{2+}{}_{(aq)} + 2\ e^- \rightarrow A_{(s)}$ **(4 marks)**

b. The identities of the four unknown metals are as follows: X is Ag, D is Pb, Z is Fe, A is Zn. **(2 marks)**

3. a. reduction
   b. oxidation
   c. reduction
   d. reduction
   e. oxidation **(5 marks)**

4. Historically speaking, oxidation meant a reaction in which oxygen was one of the reactants. Reduction implied that a large amount of a chemical compound was being reduced down to a smaller amount of a pure element. **(2 marks)**

5. No. You could not successfully store a solution of acidified potassium permanganate in a tin can because a spontaneous redox reaction would occur that would disintegrate the tin can.

OA **SOA** **OA** **OA**

$Sn_{(s)}$, $K^+_{(aq)}$, $MnO_4^-{}_{(aq)}$, $H^+_{(aq)}$, $H_2O_{(l)}$

SRA **RA**

$$2\left(MnO_4^-{}_{(aq)} + 8\,H^+_{(aq)} + 5\,e^- \rightarrow Mn^{2+}_{(aq)} + 4\,H_2O_{(l)}\right)$$
$$5\left(Sn_{(s)} \rightarrow Sn^{2+}_{(aq)} + 2\,e^-\right)$$
$$2\,MnO_4^-{}_{(aq)} + 16\,H^+_{(aq)} + 5\,Sn_{(s)} \xrightarrow{S} 2\,Mn^{2+}_{(aq)} + 8\,H_2O_{(l)} + 5\,Sn^{2+}_{(aq)}$$ **(4 marks)**

6. a. **SOA** **OA**

$Zn_{(s)}$, $Au^{3+}_{(aq)}$, $Cl^-_{(aq)}$, $H_2O_{(l)}$

SRA **RA** **RA** **RA**

$$2\left(Au^{3+}_{(aq)} + 3\,e^- \rightarrow Au_{(s)}\right)$$
$$3\left(Zn_{(s)} \rightarrow Zn^{2+}_{(aq)} + 2\,e^-\right)$$
$$2\,Au^{3+}_{(aq)} + 3\,Zn_{(s)} \xrightarrow{S} 2\,Au_{(s)} + 3\,Zn^{2+}_{(aq)}$$ **(3 marks)**

SOA **OA** **OA**

b. $Cl_{2(g)}$, $H_{2(g)}$, $OH^-_{(aq)}$, $Na^+_{(aq)}$, $H_2O_{(l)}$

RA **SRA** **RA** **RA**

$$Cl_{2(g)} + 2\,e^- \rightarrow 2\,Cl^-_{(aq)}$$
$$H_{2(g)} + 2\,OH^-_{(aq)} \rightarrow 2\,H_2O_{(l)} + 2\,e^-$$
$$Cl_{2(g)} + H_{2(g)} + 2\,OH^-_{(aq)} \xrightarrow{S} 2\,Cl^-_{(aq)} + 2\,H_2O_{(l)}$$ **(3 marks)**

c. $H^+_{(aq)}$, $ClO_4^-{}_{(aq)}$, $H_2O_{2(l)}$, $H_2O_{(l)}$

SOA, SOA, OA, SRA, RA

$$ClO_4^-{}_{(aq)} + 8\,H^+_{(aq)} + 8\,e^- \rightarrow Cl^-_{(aq)} + 4\,H_2O_{(l)}$$
$$4\left(H_2O_{2(l)} \rightarrow O_{2(g)} + 2\,H^+_{(aq)} + 2\,e^-\right)$$
$$ClO_4^-{}_{(aq)} + 4\,H_2O_{2(l)} \xrightarrow{S} Cl^-_{(aq)} + 4\,H_2O_{(l)} + 4\,O_{2(g)}$$

(3 marks)

d. $H^+_{(aq)}$, $Cl^-_{(aq)}$, $H_2O_{(l)}$, $Cu_{(s)}$

RA, RA, RA, SRA

$$2\,H^+_{(aq)} + 2\,e^- \rightarrow H_{2(g)}$$
$$Cu_{(s)} \rightarrow Cu^{2+}_{(aq)} + 2\,e^-$$
$$2\,H^+_{(aq)} + Cu_{(s)} \xrightarrow{NS} H_{2(g)} + Cu^{2+}_{(aq)}$$

(3 marks)

7. No. The pen did not successfully etch the piece of copper foil because there would be no reaction between the hydrochloric acid and the copper metal. **(2 marks)**

8. The products of the reaction are predicted to be hydrogen gas, hydroxide ions, and sodium ions.

SOA

$Na_{(s)}$, $H_2O_{(l)}$

SRA RA

$$2\,H_2O_{(l)} + 2\,e^- \rightarrow H_{2(g)} + 2\,OH^-_{(aq)}$$
$$2\left(Na_{(s)} \rightarrow Na^+_{(aq)} + 1\,e^-\right)$$
$$2\,H_2O_{(l)} + 2\,Na_{(s)} \xrightarrow{S} H_{2(g)} + 2\,OH^-_{(aq)} + 2\,Na^+_{(aq)}$$

The following diagnostic tests could be used to identify the products:

- Hydrogen gas when collected in a tube would give off a pop sound when ignited.
- The basic solution would turn red litmus paper blue.
- A flame test of the product solution would give a yellow flame, indicating the presence of sodium ions. **(5 marks)**

Section 2: Redox Applications

Key Concepts

This section initially deals with quantitative aspects (stoichiometry) of electrochemistry. It begins with an introduction to titration and the terms important to titrations. In Activity 2 oxidation numbers are introduced and their usefulness in balancing reactions is explored. The section ends with a look at the different ways of balancing redox reactions.

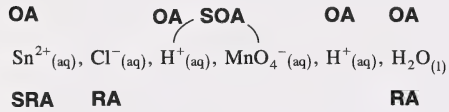
Teaching Suggestions

- It is important to review the concept and techniques involved in titration in Activity 1. The definitions of *titrant, endpoint, equivalence point*, and *primary standard* should be stressed. The idea of stoichiometry and redox reactions are very important here. Therefore, the steps involved in stoichiometry should be reviewed.
- It is important to provide several opportunities for practice in dealing with oxidation numbers.
- Students benefit from lots of practice in balancing redox equations with oxidation numbers and half-reactions.

Section 2: Assignment Answer Key (40 marks)

1. oxidized **(1 mark)**

2. Both oxidation and reduction must take place for a redox reaction to occur. One substance cannot gain electrons without another substance having first lost those electrons. **(2 marks)**

3. 

   a. The oxidizing agent in the reaction would be $H^+_{(aq)} + MnO_4^-{}_{(aq)}$; the reducing agent would be $Sn^{2+}_{(aq)}$. **(2 marks)**

   b. The colour change that would signify the endpoint would be colourless to pink (or pink to purple). **(1 mark)**

   c. The potassium permanganate is the titrant. **(1 mark)**

   d. The equivalence point would be the point at which chemically equivalent amounts of the oxidizing and reducing agents are present.

$$2\left(MnO_4^-{}_{(aq)} + 8\,H^+_{(aq)} + 5\,e^- \rightarrow Mn^{2+}_{(aq)} + 4\,H_2O_{(l)}\right)$$
$$5\left(Sn^{2+}_{(aq)} \rightarrow Sn^{4+}_{(aq)} + 2\,e^-\right)$$
$$2\,MnO_4^-{}_{(aq)} + 16\,H^+_{(aq)} + 5\,Sn^{2+}_{(aq)} \rightarrow 2\,Mn^{2+}_{(aq)} + 8\,H_2O_{(l)} + 5\,Sn^{4+}_{(aq)}$$

   The equivalence point is reached when there is a ratio of 2 mol of $MnO_4^-{}_{(aq)}$ to 5 mol of $Sn^{2+}_{(aq)}$ present. **(2 marks)**

4. a. redox
   b. not redox
   c. not redox
   d. redox **(4 marks)**

5. a. $\overset{+1}{H}\overset{+3}{P}\overset{-2}{O_3}^{2-}$; P = +3

b. $\overset{+1}{H_3}\overset{+1}{P}\overset{-2}{O_2}$; P = +1

c. $\overset{+5}{P_4}\overset{-2}{O_{10}}$; P = +5

d. $\overset{+1}{Na_2}\overset{+1}{H}\overset{+5}{P}\overset{-2}{O_4}$; P = +5 **(4 marks)**

SOA **OA**

6. $Au^{3+}_{(aq)}$, $NO_3^-{}_{(aq)}$, $OH^-_{(aq)}$, $H_{2(g)}$, $H_2O_{(l)}$

RA SRA RA RA

$$2\left(Au^{3+}_{(aq)} + 3\,e^- \rightarrow Au_{(s)}\right)$$
$$3\left(H_{2(g)} + 2\,OH^-_{(aq)} \rightarrow 2\,H_2O_{(l)} + 2\,e^-\right)$$
$$2\,Au^{3+}_{(aq)} + 3\,H_{2(g)} + 6\,OH^-_{(aq)} \xrightarrow{s} 2\,Au_{(s)} + 6\,H_2O_{(l)}$$

(3 marks)

7. $1\,\overset{+1}{Na}\overset{+5}{I}\overset{-2}{O_3}_{(aq)} + 5\,\overset{+1}{Na}\overset{-1}{I}_{(aq)} + 6\,\overset{+1}{H}\overset{-1}{Cl}_{(aq)} \rightarrow 6\,\overset{+1}{Na}\overset{-1}{Cl}_{(aq)} + 3\,\overset{0}{I_2}_{(s)} + 3\,\overset{+1}{H_2}\overset{-2}{O}_{(l)}$

$5\,e^-$ / I $\quad$ $1\,e^-$ / I

$5\,e^-$ / $NaIO_3$ $\quad$ $1\,e^-$ / NaI

(×1) $\quad$ (×5) **(3 marks)**

8. $H_3AsO_{3(aq)} + Cr_2O_7^{2-}{}_{(aq)} \rightarrow H_3AsO_{4(aq)} + Cr^{3+}_{(aq)}$ (unbalanced)

$$3\left(H_2O_{(l)} + H_3AsO_{3(aq)} \rightarrow H_3AsO_{4(aq)} + 2\,H^+_{(aq)} + 2\,e^-\right)$$
$$6\,e^- + 14\,H^+_{(aq)} + Cr_2O_7^{2-}{}_{(aq)} \rightarrow 2\,Cr^{3+}_{(aq)} + 7\,H_2O_{(l)}$$
$$3\,H_3AsO_{3(aq)} + 8\,H^+_{(aq)} + Cr_2O_7^{2-}{}_{(aq)} \rightarrow 3\,H_3AsO_{4(aq)} + 2\,Cr^{3+}_{(aq)} + 4\,H_2O_{(l)}$$

(3 marks)

9. $12\,\overset{+1}{H_2}\overset{+5}{P}\overset{-2}{O_4}^-_{(aq)} + 12\,\overset{+1}{H}^+_{(aq)} + 10\,\overset{-1}{Br}^-_{(aq)} \rightarrow 3\,\overset{0}{P_4}_{(s)} + 18\,\overset{+1}{H_2}\overset{-2}{O}_{(l)} + 10\,\overset{+5}{Br}\overset{-2}{O_3}^-_{(aq)}$

$5\,e^-$ / P $\quad$ $6\,e^-$ / Br^-

$5\,e^-$ / $H_2PO_4^-$

$$\text{number of electrons transferred} = \frac{5\text{ mol } e^-}{1\text{ mol } H_2PO_4^-} \times 1.20\text{ mol } H_2PO_4^-$$
$$= 6.00\text{ mol } e^-$$

6	.	0	0

(2 marks)

10. $\overset{+5}{\underset{+5}{P}}\overset{-1}{Cl}_{5(s)} + 2\ \overset{0}{Na}_{(s)} \rightarrow \overset{+3}{\underset{+3}{P}}\overset{-1}{Cl}_{3(s)} + 2\ \overset{+1}{Na}\overset{-1}{Cl}_{(s)} + 729.5\ kJ$

OA **RA**

heat produced : $\Delta H = \dfrac{729.5\ kJ}{2\ \cancel{mol\ Na}} \times 0.235\ \cancel{mol\ Na}$

$= 85.7\ kJ$ The heat produced is 85.7 kJ. **(2 marks)**

11. average volume $KMnO_{4(aq)} = \dfrac{(20.3 + 20.2 + 20.4)\ mL}{3}$

$= 20.3\ mL$

OA **OA** **SOA** **OA** **OA**

$Sn^{2+}_{(aq)}$, $NO_3^-{}_{(aq)}$, $K^+_{(aq)}$, $MnO_4^-{}_{(aq)}$, $H^+_{(aq)}$, $H_2O_{(l)}$

SRA **RA**

$$2\left(MnO_4^-{}_{(aq)} + 8\ H^+_{(aq)} + 5\ e^- \rightarrow Mn^{2+}_{(aq)} + 4\ H_2O_{(l)}\right)$$
$$5\left(Sn^{2+}_{(aq)} \rightarrow Sn^{4+}_{(aq)} + 2\ e^-\right)$$

$$2\ MnO_4^-{}_{(aq)} + 16\ H^+_{(aq)} + 5\ Sn^{2+}_{(aq)} \xrightarrow{s} 2\ Mn^{2+}_{(aq)} + 8\ H_2O_{(l)} + 5\ Sn^{4+}_{(aq)}$$

20.3 mL	25.0 mL
0.008 00 mol/L	$C = ?$

$$C_{(Sn^{2+})} = 20.3\ \cancel{mL\ MnO_4^-} \times \frac{0.008\ 00\ \cancel{mol\ MnO_4^-}}{1\ \cancel{L\ MnO_4^-}} \times \frac{5\ mol\ \cancel{Sn^{2+}}}{2\ \cancel{mol\ MnO_4^-}} \times \frac{1}{25.0\ \cancel{mL}\ \cancel{Sn^{2+}}}$$

$= 0.0162\ mol/L$ The concentration of $Sn^{2+}_{(aq)}$ is 0.0162 mol/L. **(6 marks)**

OA **SOA** **OA** **OA**

12. $Fe_{(s)}$, $K^+_{(aq)}$, $Cr_2O_7^{2-}{}_{(aq)}$, $H^+_{(aq)}$, $H_2O_{(l)}$

SRA **RA**

$$6\ e^- + 14\ H^+_{(aq)} + Cr_2O_7^{2-}{}_{(aq)} \rightarrow 2\ Cr^{3+}_{(aq)} + 7\ H_2O_{(l)}$$
$$3\left(Fe_{(s)} \rightarrow Fe^{2+}_{(aq)} + 2\ e^-\right)$$

$$14\ H^+_{(aq)} + Cr_2O_7^{2-}{}_{(aq)} + 3\ Fe_{(s)} \xrightarrow{s} 2\ Cr^{3+}_{(aq)} + 7\ H_2O_{(l)} + 3\ Fe^{2+}_{(aq)}$$

0.250 mol/L	55.85 g/mol
50.0 mL	$m = ?$
(0.0500 L)	

$$m_{(Fe)} = 0.0500\ \cancel{L\ Cr_2O_7^{2-}} \times \frac{0.250\ \cancel{mol\ Cr_2O_7^{2-}}}{\cancel{L\ Cr_2O_7^{2-}}} \times \frac{3\ \cancel{mol\ Fe}}{1\ \cancel{mol\ Cr_2O_7^{2-}}} \times \frac{55.85\ g}{1\ \cancel{mol\ Fe}}$$

$= 2.09\ g$ A mass of 2.09 g of $Fe_{(s)}$ will be oxidized. **(4 marks)**

Final Module Assignment Answer Key (20 marks)

Multiple Choice

1. D 2. C 3. A 4. D 5. A **(5 marks)**

Numerical Response

6. | 2 | 4 | 1 | 3 | **(1 mark)**

7. | 6 | 4 | 4 | 6 | **(1 mark)**

Written Response

8. No. The method would not work using a copper pan because the reaction between $Ag_2S_{(s)}$ and $Cu_{(s)}$ is non-spontaneous.

SOA **OA**

$Ag_2S_{(s)}$, $Cu_{(s)}$, $H_2O_{(l)}$

SRA **RA**

$$Ag_2S_{(s)} + 2\,e^- \rightarrow 2\,Ag_{(s)} + S^{2-}{}_{(aq)}$$
$$Cu_{(s)} \rightarrow Cu^{2+}{}_{(aq)} + 2\,e^-$$
$$Ag_2S_{(s)} + Cu_{(s)} \xrightarrow{NS} 2\,Ag_{(s)} + S^{2-}{}_{(aq)} + Cu^{2+}{}_{(aq)}$$ **(4 marks)**

SOA **OA**

9. a. $Al_{(s)}$, $Cu^{2+}{}_{(aq)}$, $Cl^-{}_{(aq)}$, $H_2O_{(l)}$

SRA **RA** **RA** **RA**

$$3\left(Cu^{2+}{}_{(aq)} + 2\,e^- \rightarrow Cu_{(s)}\right)$$
$$2\left(Al_{(s)} \rightarrow Al^{3+}{}_{(aq)} + 3\,e^-\right)$$
$$3\,Cu^{2+}{}_{(aq)} + 2\,Al_{(s)} \xrightarrow{S} 3\,Cu_{(s)} + 2\,Al^{3+}{}_{(aq)}$$ **(2 marks)**

b.
$$\Delta H_r = q$$
$$\begin{pmatrix}\text{Al}\\ \text{reaction}\end{pmatrix}\begin{pmatrix}\text{calorimeter}\\ \text{water}\end{pmatrix}$$
$$nH_r = mc\Delta t$$
$$\left(0.45\text{ g}\times\frac{1\text{ mol Al}}{26.98\text{ g}}\right)H_r = 0.1000\text{ kg}\times\frac{4.19\text{ kJ}}{\text{kg}\bullet^\circ\text{C}}\times(46.5-24.0)^\circ\text{C}$$
$$H_r = \frac{9.4275\text{ kJ}}{0.016\,68\text{ mol Al}}$$
$$= 5.7\times10^2\text{ kJ/mol Al}$$

The molar heat of reaction of aluminum is -5.7×10^2 kJ/mol. **(4 marks)**

c. $3\,Cu^{2+}_{(aq)} + 2\,Al_{(s)} \rightarrow 3\,Cu_{(s)} + 2\,Al^{3+}_{(aq)} + 1.1\times10^{3}\ kJ$

or

$3\,Cu^{2+}_{(aq)} + 2\,Al_{(s)} \rightarrow 3\,Cu_{(s)} + 2\,Al^{3+}_{(aq)} \quad \Delta H_r = -1.1\times10^{3}\ kJ$ **(1 mark)**

d. $3\,\overset{+2}{Cu}{}^{2+}_{(aq)} + 2\,\overset{0}{Al}_{(s)} \rightarrow 3\,\overset{0}{Cu}_{(s)} + 2\,\overset{+3}{Al}{}^{3+}_{(aq)} \quad \Delta H_r = -1.1\times10^{3}\ kJ$

$2\,e^- / Cu^{2+}$ $3\,e^- / Al$

$(\times3)$ $(\times2)$

$2\times3 = 6\ mol\ e^-$ transferred

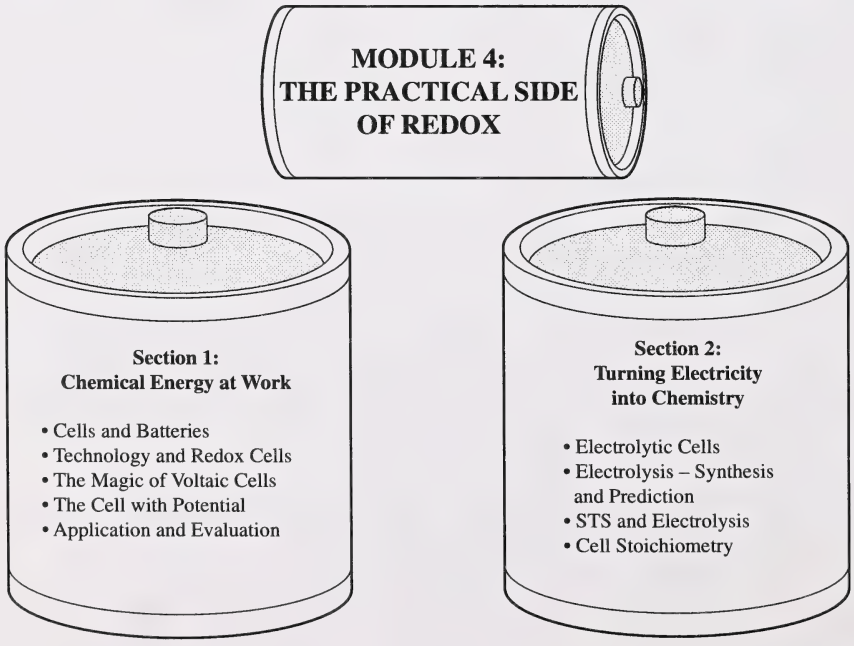
$$\frac{-1.130\times10^{3}\ kJ}{6\ mol\ e^-} = -1.9\times10^{2}\ kJ/mol\ e^-\ transferred$$

There were 1.9×10^{2} kJ of heat released per mole of electrons transferred. **(2 marks)**

Module 4: The Practical Side of Redox

Overview

There are two main emphases in this unit. The first is to develop an understanding of how an electrochemical cell works, including how to predict cell potentials. The second is to learn about the electrolytic cell and electrolysis, including related chemical calculations. Incorporated into this is a comparison of the two types of processes. This module stresses the themes of systems and change and also stresses having students develop their science skills and technological problem-solving skills. Commercial and industrial applications of redox principles are discussed and carried into the assignments.



Evaluation

The evaluation of this module will be based on two section assignments and one module assignment:

Section 1 Assignment	**40 marks**
Section 2 Assignment	**40 marks**
Final Module Assignment	**20 marks**
TOTAL	**100 marks**

Materials and Equipment

The following is a list of materials necessary for completing the investigations and activities in Module 5. Amounts stated represent requirements per student.

Section 1: Activity 1

Investigation: Using a Multimeter

- multimeter
- cup of tap water
- cup of salt water

Investigation 13.1: Demonstration of a Simple Electric Cell

A list of materials is given on page 387 of *Nelson Chemistry*. The multimeter will be used instead of the voltmeter and ammeter.

- multimeter
- steel wool

Note: Make sure all of your connections are good when you use the multimeter. In this activity, the voltage and especially the current readings will fluctuate wildly and have a very large spread because of such things as differences in how juicy the fruit is, etc. The important thing is only to see that you do get a voltage and current reading; the actual numerical results are not important.

Section 1: Activity 2

Investigation 13.2: Designing an Electric Cell

- copper wire or pipe, galvanized metal, lead weight, iron nail, and wooden pencil (graphite core) (Metal strips of the equivalent elements could be used instead.)
- aluminum can
- steel wool
- 5 mL (1 tsp.) salt
- 5 mL (1 tsp.) baking soda
- 150 mL household vinegar
- water
- 3 glasses or beakers
- tin snips or can-opener
- multimeter
- alligator clips and leads

Note: To remove the lid from the aluminum can, you can also just squeeze and bend the whole can back and forth until it breaks in half. The size of the can is then much smaller, but the results should be the same. Caution the students on the sharp edges.

Section 1: Activity 3

Investigation 13.3: Demonstration of a Voltaic Cell

- 60 mL of 0.10 mol/L $CuSO_{4(aq)}$
- 60 mL of 0.10 mol/L $ZnSO_{4(aq)}$
- 60 mL of 0.10 mol/L $NaNO_{3(aq)}$
- 15 cm dialysis tubing (or 30 cm if you expect a mistake or two) or porous cup
- 1 U-tube with cotton batting plugs or paper towel
- (4) 100 mL or 250 mL beakers
- multimeter
- alligator clips and leads
- steel wool
- tweezers or tongs
- strips of copper and zinc (one each)
- scissors
- string or thread

Note: You get excellent results with the dialysis tubing if you make sure the knots are tied well on the tubing. You may also wish to include $Ag_{(s)}$ and $AgNO_{3(aq)}$ if you have them available.

Section 1: Activity 5

Investigation 13.4: Testing Voltaic Cells

- multimeter
- (4) 100 mL or 250 mL beakers
- 60 mL each of 0.10 mol/L $CuSO_{4(aq)}$, $ZnSO_{4(aq)}$, $Pb(NO_3)_{2(aq)}$, and $NaNO_{3(aq)}$
- steel wool
- strips of zinc, copper, and lead
- alligator clips and leads

Note: You can use a paper towel salt bridge soaked in $NaNO_{3(aq)}$ or dialysis tubing instead of a U-tube to get your results. The small beakers work just as well as larger ones. You can use $Ag_{(s)}$ and $AgNO_{3(aq)}$ as well if these are available.

Section 2: Activity 1

Investigation 13.5: A Potassium Iodide Electrolytic Cell

- 1.7 g (1 mL) KI in 20 mL H_2O/trial
- universal low voltage AC adapter
- 2 pencil lead electrodes
- red and blue litmus paper
- U-tube
- 2 alligator clips and leads
- 250 mL beaker
- ring stand with two clamps to hold electrodes

Note: Remember to plug in the AC adapter once the entire experiment has been set up and initial observations are complete.

Section 2: Activity 2

Investigation 13.6: Demonstration of Electrolysis

- about 2 mL each (1.5 g) of $CuSO_{4(s)}$, $Na_2SO_{4(s)}$, $NaCl_{(s)}$
- universal low voltage AC adapter
- 2 pencil lead electrodes
- red and blue litmus paper
- water
- U-tube or 100 mL beaker
- 2 alligator clips and leads
- 250 mL beaker
- ring stand with two clamps to hold electrodes

Note: You may find it necessary to increase the voltage to 4.5 V in the $CuSO_{4(aq)}$ solution in order to get appreciable results. The others should work well on the 3 V setting.

Section 2: Activity 3

Investigation 13.7: Copper Plating

- about 15 g of $CuSO_{4(s)}$
- universal low voltage AC adapter
- 1 pencil lead electrode
- U-tube
- large washers (6 minimum), or paper clips, or screws, or keys – all should be stainless steel or brass
- 4 (100 mL or 250 mL) beakers
- 2 alligator clips and leads
- steel wool
- ring stand with two clamps to hold electrodes

Note: If you use washers for electroplating, you can do a large number of tests without worrying about varying the cathode each time. The washers are also easy to polish. There is a lot of flexibility with this lab, so the quantities given here are what correspond to the Appendix answers.

Additional Resources

Abatemarco, Fred, ed. *Popular Science*, July 1992, February 1993, June 1993. New York, N.Y. 10016: Times Mirror Magazines, Inc.

Austin, George T., ed. 1984. *Shreve's Chemical Process Industries*. 5th ed. Toronto: McGraw-Hill Inc.

Brady, James E., and John R. Holum. 1988. *Fundamentals of Chemistry*. 3d ed. Toronto: John Wiley & Sons, Inc.

McDuffie, Thomas E., Jr., and Jacqueline Anderson. 1980. *Chemical Experiments from Daily Life*. Portland, Maine: J. Weston Walch, Publisher.

Robson, David P., ed. April 1993. *Chem Matters*. Department L-0011, Columbus, OH 43268-0011: American Chemical Society.

Weast, Robert C. 1975. *Handbook of Chemistry and Physics*. 56th ed. Cleveland, OH: CRC Press.

Other

Industrial Waste Branch, Government of Alberta. Edmonton, Alberta.

Sherritt Inc. Fort Saskatchewan, Alberta.

The Answer Centre, TransAlta Utilities, Calgary, Alberta, 1-800-667-2345.

Possible Media

Videos

ACME School of Stuff. (1988) TV Ontario. (ACCESS Network)
Includes Program 3: Batteries, Water, and Fuel Injection

CHEM Study Video. (1989) Ward's Natural Science Ltd.
Includes Electrochemical Cells, Vol. 9.

Electrochemistry Series. (1986) TV Ontario. (ACCESS Network)
Includes Program 1: The Building Blocks of Electrochemistry (VC324801)
Program 2: Electrochemical Cells (VC324802)
Program 3: Designing Electrochemical Cells (VC324803)
Program 6: Electroplating (VC324806)

Section 1: Chemical Energy at Work

Key Concepts

In this section, students will learn the parts of a voltaic cell, how the parts work together, and how to predict the potential difference of an electrochemical cell. In the first activity, they will learn the three main components of all electrochemical cells. From there they will use technological problem-solving skills to improve on the design of the cell. The students will use these skills to evaluate commercial and standard voltaic cells. This will lead them into a discussion on potential difference and standard electrode potentials. The section ends with an activity that introduces how the cell relates to corrosion and cathodic protection. A discussion of oxidation potentials is introduced at this point.

Teaching Suggestions

- The two main concepts to get across in Activity 1 are the main parts of a cell completing a circuit and the idea that chemical change occurs and work is done because electrons are transferred through a wire rather than by direct contact. That is, the half-reactions discussed in Module 3 are now separated rather than in direct contact.

- In Activity 2 an interesting extension of the aluminum-can cell investigation is to challenge the class, using only safe household materials, to see which group can build the cell with the highest voltage. If nobody thinks of it, you can give a hint to somebody finishing early that they might want to connect two cells together. This way, they can figure out with a hands-on approach how cells hooked together in series work to make batteries.

- Activity 3 is an excellent time to start the class with the TV Ontario video Program 2 Electrochemical Cells in the *Electrochemistry* series (see videos resource list). This video will begin to tie the previous module more closely to this one and give an overview of the parts and functions of the parts of a voltaic cell.

- A class could try the following activity in Activity 4:

  Make two decks of cards, one with a RED CAT on the back, and the other with AN OX on the back. On the front of each RED CAT card, write only the reactants of the reduction half-reaction with its reduction potential. On the front of each AN OX card, write only the products of a reduction half-reaction with its electrode potential. At the start of class, hand out a card to each student making sure you hand out as many RED CAT's as AN OX's. Give the students three to five minutes to find a partner with whom they can create the largest cell potential. From this activity, the students should learn how to calculate cell potential on their own (especially when some big numbers actually come back negative).

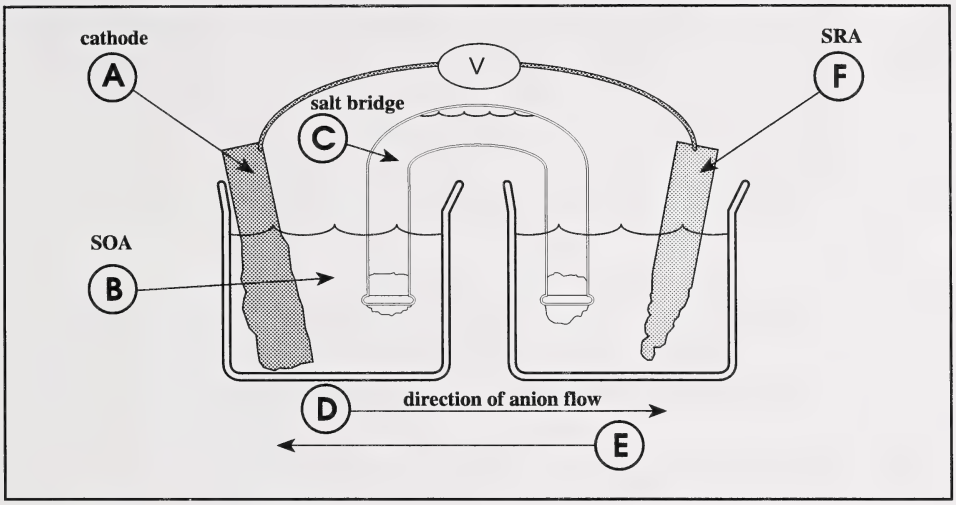
  Students may raise questions such as the following:

  – Why are some people still unpaired?
  – Why did some people change partners?
  – What does this say about the relative strengths of oxidizing agents and reducing agents?
  – Why are some big numbers negative?

- In Activity 5, as a modification of Investigation 13.4, you may want to change this lab into one where the students have to identify the solutions and their electrodes before they try to build the cell. The students are only given the list of possible metals and solutions. This would force them to review the relative reactivities from Module 3 before being able to start the lab. In this lab, if you are not reusing the solutions, encourage students to experiment what would happen to the electrode potential if you used one metal in a different electrolyte. Does the voltage go up or down? Why?

Section 1: Assignment Answer Key (40 marks)

1. a.



(5 marks)

b. The ions initially present in the solution indicated by point (B) would be $Ag^{+}_{(aq)}$ **and** $NO_3^{-}{}_{(aq)}$. **(1 mark)**

c. The ions initially present in the salt bridge would be $Na^{+}_{(aq)}$ **and** $NO_3^{-}{}_{(aq)}$. **(1 mark)**

d. The ions that would migrate through the salt bridge from each solution would be $Zn^{2+}_{(aq)}$ **and** $NO_3^{-}{}_{(aq)}$. **(2 marks)**

e. The direction of flow of electrons would be towards the electrode labelled letter (A). **(1 mark)**

f. $\left[Ag^{+}_{(aq)}\right]$ decreases, $\left[Zn^{2+}_{(aq)}\right]$ increases, and $\left[Na^{+}_{(aq)}\right]$ and $\left[NO_3^{-}{}_{(aq)}\right]$ remain the same. **(4 marks)**

g. $\Delta E^\circ = E^\circ_r(\text{cathode}) - E^\circ_r(\text{anode})$

$= +0.80\text{ V} - (-0.76\text{ V})$

$= +1.56\text{ V}$

The standard cell potential is +1.56 V. **(2 marks)**

or,

$2\left(Ag^{+}_{(aq)} + 1\,e^{-} \rightarrow Ag_{(s)}\right)$ $\quad E^\circ_r = +0.80\text{ V}$

$Zn_{(s)} \rightarrow Zn^{2+}_{(aq)} + 2\,e^{-}$ $\quad E^\circ_{ox} = +0.76\text{ V}$

$2\,Ag^{+}_{(aq)} + Zn_{(s)} \rightarrow 2\,Ag_{(s)} + Zn^{2+}_{(aq)}$ $\quad \Delta E^\circ = +1.56\text{ V}$

2. a. $\Delta E^\circ = +0.80\text{ V} - (-0.40\text{ V})$

$= +1.20\text{ V}$

The potential difference is +1.20 V. **(2 marks)**

b. $\Delta E^\circ = +0.34\text{ V} - (-0.36\text{ V})$

$= +0.70\text{ V}$

The potential difference is +0.70 V. **(2 marks)**

3. It would not affect the potential difference. Since a change in the reference electrode would change all half-cell potentials by an equal amount, the relative difference between half-cell potentials would remain the same.

If $F_{2(g)} + 2\,e^{-} \rightarrow 2\,F^{-}_{(aq)}$ $\quad E^\circ_r = 0.00$, then the E°_r for each of the cadmium and silver half-cells would be 2.87 V higher.

Therefore, $\Delta E^\circ = (0.34\text{ V} + 2.87\text{ V}) - (-0.36\text{ V} + 2.87\text{ V})$

$= +0.70\text{ V}$ This value is the same as before. **(2 marks)**

4. a. **Anode:** $2\left(Fe_{(s)} \rightarrow Fe^{3+}_{(aq)} + 3\,e^-\right)$ $E°_{ox} = +0.04\ V$

Cathode: $3\left(F_{2(g)} + 2\,H^+_{(aq)} + 2\,e^- \rightarrow HF_{(aq)}\right)$ $E°_r = +3.03\ V$

Net Reaction: $2\,Fe_{(s)} + 3\,F_{2(g)} + 6\,H^+_{(aq)} \rightarrow 2\,Fe^{3+}_{(aq)} + 3\,HF_{(aq)}$ $\Delta E° = +3.07\ V$

or, $\Delta E° = E°_r(\text{cathode}) - E°_r(\text{anode})$

$= +3.03\ V - (-0.04\ V)$

$= +3.07\ V$ The net cell potential is $+3.07\ V$. **(3 marks)**

b. **Anode:** $H_2SO_{3(aq)} + H_2O_{(l)} \rightarrow SO_4^{2-}{}_{(aq)} + 4\,H^+_{(aq)} + 2\,e^-$ $E°_{ox} = -0.17\ V$

Cathode: $2\left(NO_3^-{}_{(aq)} + 2\,H^+_{(aq)} + e^- \rightarrow NO_{2(g)} + H_2O_{(l)}\right)$ $E°_r = +0.80\ V$

Net Reaction: $H_2SO_{3(aq)} + 2\,NO_3^-{}_{(aq)} \rightarrow SO_4^{2-}{}_{(aq)} + 2\,NO_{2(g)} + H_2O_{(l)}$ $\Delta E° = +0.63\ V$

or, $\Delta E° = E°_r(\text{cathode}) - E°_r(\text{anode})$

$= +0.80\ V - (+0.17\ V)$

$= +0.63\ V$ The net cell potential is $+0.63\ V$. **(3 marks)**

5. a. Since the blue had intensified, that means $Cu_{(s)}$ had been oxidized. Therefore copper is the anode. The unknown metal is the cathode, which means it is 1.13 V above the copper electrode potential of 0.34 V. Therefore, the reduction potential of the unknown metal is $E°_r = 0.34\ V + 1.13\ V = +1.47\ V$.

or, $\Delta E° = E°_r(\text{cathode}) - E°_r(\text{anode})$

$E°_r(\text{cathode}) = \Delta E° + E°_r(\text{anode})$

$= 1.13\ V + 0.34\ V$

$= +1.47\ V$ The reduction potential of the unknown metal is $+1.47\ V$. **(2 marks)**

b. The unknown metal is most likely gold because it is the only metal that has a theoretical potential close to the electrode potential of +1.47 V. **(1 mark)**

6. a. Zinc would cathodically protect the fishing trawler bottom because it is a stronger reducing agent than the iron in the hull. The zinc would oxidize and act as an anode, forcing the iron bottom to be a cathode and remain unreacted. Silver is a weaker reducing agent and would not work. **(2 marks)**

b. Method 1: Place one grey metal sample on top of the other, separated by a piece of saltwater-soaked paper towel. Wrap the two samples together with copper wire. The metal that starts to visibly corrode is the zinc because zinc is the stronger reducing agent and will therefore be oxidized.

Method 2: Use the iron sample as one electrode, and one of the unknown metals as the other electrode. Immerse each in a pail of saltwater. Connect the two solutions by a paper towel soaked in saltwater. Attach the multimeter to complete the circuit and to determine the potential difference. If the iron is the cathode (connected to the positive terminal), then the grey metal is zinc. If the iron is the anode, then the grey metal is silver.

or, If the clear solution starts to turn an orange-brown colour after a period of time or the iron sample starts to corrode, then the grey metal is silver. If the grey metal starts to corrode, then the metal is zinc. **(3 marks)**

7. In the $X_{(s)} \mid X^{2+}_{(aq)} \parallel Y^{2+}_{(aq)} \mid Y_{(s)}$ cell, $X_{(s)}$ is the anode. Therefore Y is 0.50 V above X on the redox half-reactions table. In the $Z_{(s)} \mid Z^{2+}_{(aq)} \parallel X^{2+}_{(aq)} \mid X_{(s)}$ cell, X is the cathode. Therefore Z is 0.14 V below X on the redox table. This means that for the $Z_{(s)} \mid Z^{2+}_{(aq)} \parallel Y^{2+}_{(aq)} \mid Y_{(s)}$ cell, $Z_{(s)}$ is the anode and $Y_{(s)}$ is the cathode. The net potential difference is the sum of 0.14 V and 0.50 V which means that $\Delta E^\circ = 0.64$ V. **(4 marks)**

Section 2: Turning Electricity into Chemistry

Key Concepts

The two main emphases in this section are to study the basic operational principles of an electrolytic cell through comparisons with the voltaic cell, and to learn how to solve stoichiometry questions based on calculating the number of moles of electrons transferred in a redox reaction. This means the students must learn to work with current, time, and Faraday's constant.

Near the end of this unit, it would be a good idea to incorporate concepts from the energy modules, to help discuss some of the energy principles involved in electrochemical cells.

Teaching Suggestions

- To start Activity 1, set up a demonstration of an operating electrochemical cell. Have the students predict what would happen when you change various parts of the cell. From this, they can derive what conditions must be necessary to ensure an operational voltaic cell. When the cell doesn't work, you can begin to ask *why* questions so as to incorporate some of the characteristics of an electrolytic cell.
- In Activity 2, besides having the students do the investigation in this activity, make sure you demonstrate Hoffman's apparatus to them afterwards so they can see the relative proportions of hydrogen to oxygen and test for these gases. A field trip to the Dow Chemical Canada Ltd. plant in Fort Saskatchewan would reinforce how the redox concepts are put to use. Dow welcomes student tours.
- If time permits in Activity 3, have the students do Investigation 13.7 once with washers to determine the best conditions for electrolysis. Very good conditions can be created if you first clean the washers in 6 mol/L $HCl_{(aq)}$, then with steel wool. Add some ethanol and sulphuric acid to the copper(II) sulphate solution.
- In Activity 4, stress the fact that, as with heat in the energy unit, if the electrons are written in the balanced chemical equation, they behave just like chemicals. Calculating the number of moles of electrons is different, just like calculating moles from mass is different from calculating moles using concentration and volume.

Section 2: Assignment Answer Key (40 marks)

1. a. False. A salt bridge is not required because the reaction is non-spontaneous.

   b. True, since electrons are lost.

   c. False. The strongest oxidizing agent (reduction half-reaction) must be equal to or lower than the strongest reducing agent in an electrolytic reaction.

   d. False. The $E^\circ_r(Cd) = -0.40$ V only for 1.0 mol/L solutions of $Cd^{2+}_{(aq)}$ with $Cd_{(s)}$ at SATP.

   e. False. Water will react at the cathode to produce $H_{2(g)}$ and $OH^-_{(aq)}$, neither of which will increase the mass of the cathode.

f. False. Tripling the current will triple the product. Halving this will cause a net increase of one and one-half times more product (3/2), not 2/3.

g. True. Since the masses of the two metals are similar, but the charge on the cobalt is lower, this means a higher mass to charge ratio.

h. True. The minimum voltage required for the electrolysis of aqueous lithium hydroxide is 1.23 V, so 3.0 V should be enough. **(8 marks)**

2. a. Because there is no power supply, a spontaneous electrochemical cell must be set up. Iron must be the anode, so the cathode should be more inert which means it should be copper. The equations, then, are

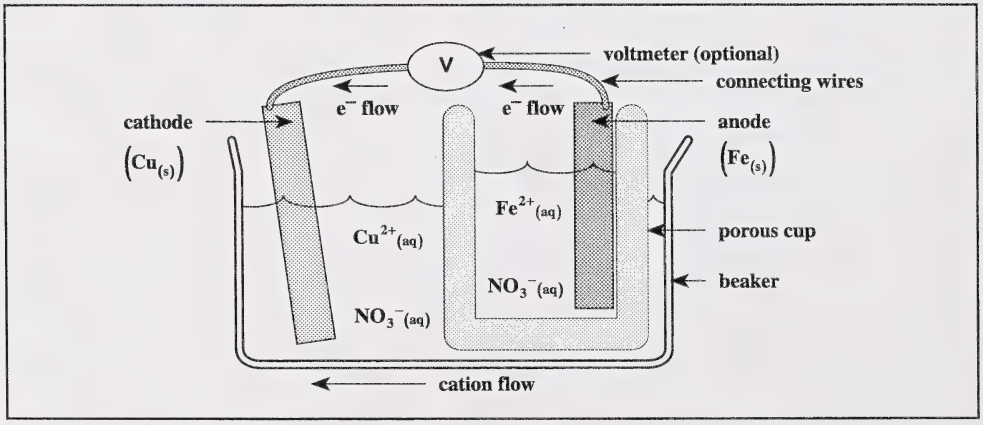
Cathode:	$Cu^{2+}_{(aq)} + 2\ e^- \rightarrow Cu_{(s)}$	$E^\circ_r = +0.34$ V
Anode:	$Fe_{(s)} \rightarrow Fe^{2+}_{(aq)} + 2\ e^-$	$E^\circ_{ox} = +0.45$ V
Net Reaction:	$Cu^{2+}_{(aq)} + Fe_{(s)} \rightarrow Cu_{(s)} + Fe^{2+}_{(aq)}$	$\Delta E^\circ = +0.79$ V **(3 marks)**

b. From part a, the $\Delta E^\circ = +0.79$ V, **or**

$$\begin{aligned}\Delta E^\circ &= E^\circ_r(\text{cathode}) - E^\circ_r(\text{anode}) \\ &= +0.34\text{ V} - (-0.45\text{ V}) \\ &= +0.79\text{ V}\end{aligned}$$

The net potential difference of the cell is +0.79 V. **(1 mark)**

c. The diagram should be similar to the following:



(6 marks)

d. Electrode A is the cathode because it gained mass. **(2 marks)**

e. Since the ratio in the following equation between $Cu_{(s)}$ and $Fe_{(s)}$ is one to one, the number of moles of $Cu_{(s)}$ gained must equal the number of moles of $Fe_{(s)}$ lost.

$$\begin{array}{lll} Cu^{2+}_{(aq)} + Fe_{(s)} & \rightarrow & Cu_{(s)} + Fe^{2+}_{(aq)} \\ 55.85\ g/mol & & 0.329\ g \\ m = ? & & 63.55\ g/mol \end{array}$$

$$m_{(Fe)} = 0.329\ \cancel{g\ Cu} \times \frac{1\ \cancel{mol\ Cu}}{63.55\ \cancel{g\ Cu}} \times \frac{1\ \cancel{mol\ Fe}}{1\ \cancel{mol\ Cu}} \times \frac{55.85\ g}{1\ \cancel{mol\ Fe}}$$

$$= 0.289\ 1369\ g$$

$$= 0.289\ g$$ The mass of $Fe_{(s)}$ lost at the anode is 0.289 g.

The total mass lost at the anode was 0.330 g. Therefore,

$$\%\ Fe = \frac{0.289\ g\ Fe\ (pure)}{0.330\ g\ Fe\ (impure)} \times 100\%$$

$$= 87.6\%$$ The impure sample is 87.6% pure iron. **(4 marks)**

f. Any two of the following qualitative observations could be stated:

- The blue colour of the copper solution should disappear.
- The colour of the cathode should become dark until a lot of copper begins to collect.
- The insoluble impurities will form a precipitate under the anode as the iron wears away.
- The colour of the $Fe^{2+}_{(aq)}$ solution will become slightly darker or more noticeable. **(2 marks)**

3. a. **SOA** **OA**

$Pt_{(s)}$, $Cu_{(s)}$, $Pb^{2+}_{(aq)}$, $NO_3^-{}_{(aq)}$, $H_2O_{(l)}$

SRA **RA**

Cathode: $Pb^{2+}_{(aq)} + 2\ e^- \rightarrow Pb_{(s)}$ $\quad E°_r = -0.13\ V$

Anode: $Cu_{(s)} \rightarrow Cu^{2+}_{(aq)} + 2\ e^-$ $\quad E°_{ox} = -0.34\ V$

Net Reaction: $Pb^{2+}_{(aq)} + Cu_{(s)} \rightarrow Pb_{(s)} + Cu^{2+}_{(aq)}$ $\quad \Delta E° = -0.47\ V$ (non-spontaneous)

or, $\Delta E° = E°_r(\text{cathode}) - E°_r(\text{anode})$

$$= -0.13\ V - (+0.34\ V)$$

$$= -0.47\ V$$ The cell potential is -0.47 V; the reaction is non-spontaneous. **(3 marks)**

b. **OA** **SOA**

$Ag_{(s)}$, $Ca^{2+}_{(aq)}$, $I^-_{(aq)}$, $H_2O_{(l)}$

RA **SRA** **RA**

Cathode: $2\ H_2O_{(l)} + 2\ e^- \rightarrow H_{2(g)} + 2\ OH^-_{(aq)}$ $\quad E°_r = -0.83\ V$

Anode: $2\ I^-_{(aq)} \rightarrow I_{2(s)} + 2\ e^-$ $\quad E°_{ox} = -0.54\ V$

Net Reaction: $2\ H_2O_{(l)} + 2\ I^-_{(aq)} \rightarrow H_{2(g)} + 2\ OH^-_{(aq)} + I_{2(s)}$ $\quad \Delta E° = -1.37\ V$ (non-spontaneous)

or, $\Delta E° = E°_r(\text{cathode}) - E°_r(\text{anode})$

$= -0.83\text{ V} - (+0.54\text{ V})$

$= -1.37\text{ V}$ The cell potential is -1.37 V; the reaction is non-spontaneous. **(3 marks)**

4. $2\,Br^-_{(l)} \rightarrow Br_{2(g)} + 2\,e^-$

159.80 g/mol	2.50 A
m = ?	45 min
	9.65×10^4 C/mol

$$m_{(Br_2)} = \frac{2.50\ \cancel{C}}{1\ \cancel{s}} \times 45\ \cancel{min} \times \frac{60\ \cancel{s}}{1\ \cancel{min}} \times \frac{1\ \cancel{mol\ e^-}}{9.65\times10^4\ \cancel{C}} \times \frac{1\ \cancel{mol\ Br_2}}{2\ \cancel{mol\ e^-}} \times \frac{159.80\text{ g}}{1\ \cancel{mol\ Br_2}}$$

$= 5.589$ g

$= 5.6$ g

or

$$n_{e^-} = \frac{It}{F}$$

$$= \frac{(2.50\text{ C/s})\left(45\text{ min} \times \frac{60\text{ s}}{1\text{ min}}\right)}{9.65\times10^4\text{ C/mol}}$$

$= 0.069\,95$ mol e^- (rounded)

$$m_{(Br_2)} = 0.069\,95\ \cancel{mol\ e^-} \times \frac{1\ \cancel{mol\ Br_2}}{2\ \cancel{mol\ e^-}} \times \frac{159.80\text{ g}}{1\ \cancel{mol\ Br_2}}$$

$= 5.6$ g

The mass of bromine produced at the anode is 5.6 g. **(4 marks)**

5. a. $\underset{\text{SRA}}{Sn_{(s)}}$, $\underset{\text{RA}}{Cu_{(s)}}$, $\underset{\text{OA}}{Mg^{2+}_{(aq)}}$, $\underset{\text{SOA}}{NO_3^-{}_{(aq)}}$, $\underset{\text{RA}}{H_2O_{(l)}}$

Since $Sn_{(s)}$ will be oxidized, the flow of electrons is from $Sn_{(s)}$ to $Cu_{(s)}$. **(2 marks)**

b. The $Sn_{(s)}$ will be the anode and will lose mass.

$Sn_{(s)} \rightarrow Sn^{2+}_{(aq)} + 2\,e^-$

3.00 g	0.275 A
118.69 g/mol	9.65×10^4 C/mol
	t = ?

$$t = 3.00\ \cancel{g\ Sn} \times \frac{1\ \cancel{mol\ Sn}}{118.69\ \cancel{g\ Sn}} \times \frac{2\ \cancel{mol\ e^-}}{1\ \cancel{mol\ Sn}} \times \frac{9.65\times10^4\ \cancel{C}}{1\ \cancel{mol\ e^-}} \times \frac{1\ \cancel{s}}{0.275\ \cancel{C}} \times \frac{1\ \cancel{min}}{60\ \cancel{s}} \times \frac{1\text{ h}}{60\ \cancel{min}}$$

$= 4.9275$ h

$= 4.93$ h

or

$$n_{e^-} = 3.00\ \cancel{g\ Sn} \times \frac{1\ \cancel{mol\ Sn}}{118.69\ \cancel{g\ Sn}} \times \frac{2\ mol\ e^-}{1\ \cancel{mol\ Sn}}$$

$$= 0.050\ 552\ mol\ e^- \text{ (rounded)}$$

$$t = \frac{n_{e^-} F}{I}$$

$$= \frac{(0.050\ 552\ mol\ e^-)(9.65 \times 10^4\ C/mol\ e^-)}{0.275\ C/s}$$

$$= 17\ 739\ s$$

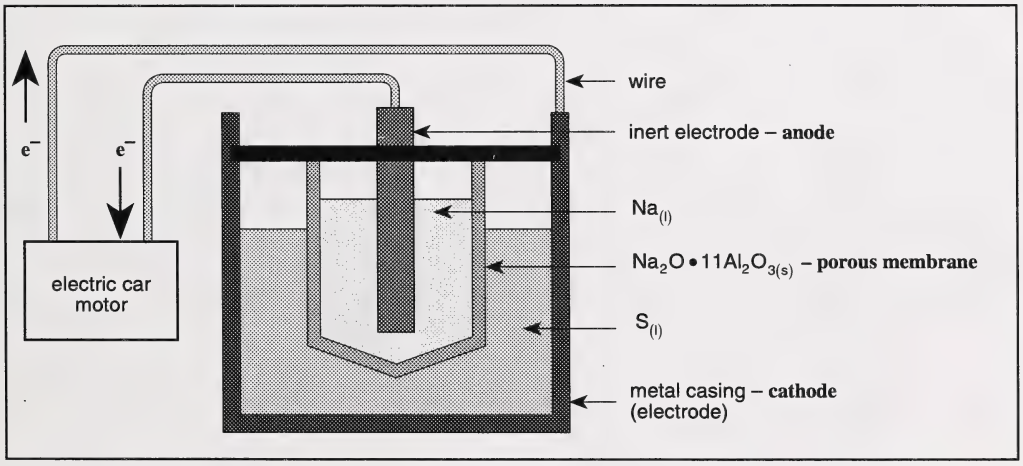
$$17\ 739\ \cancel{s} \times \frac{1\ h}{3600\ \cancel{s}}$$

$$= 4.93\ h$$

It takes 4.93 h to lose 3.00 g of $Sn_{(s)}$ at the anode. **(3 marks)**

Final Module Assignment Answer Key (20 marks)

1.



(4 marks)

2. a. $Pb_{(s)} \rightarrow Pb^{2+}_{(aq)} + 2\ e^-$

$Pb_{(s)} \rightarrow Pb^{2+}_{(aq)} + 2\ e^-$

500 g

207.20 g/mol

$2(Na_{(s)} \rightarrow Na^+_{(aq)} + e^-)$

$2\ Na_{(s)} \rightarrow 2\ Na^+_{(aq)} + 2\ e^-$

22.99 g/mol

m = ?

$$m_{(Na)} = 500\ \cancel{g\ Pb} \times \frac{1\ \cancel{mol\ Pb}}{207.20\ \cancel{g\ Pb}} \times \frac{2\ \cancel{mol\ Na}}{1\ \cancel{mol\ Pb}} \times \frac{22.99\ g}{1\ \cancel{mol\ Na}}$$

$$= 110.96\ g$$

$$= 111\ g$$ The mass of sodium oxidized is 111 g.

$Pb_{(s)} \rightarrow Pb^{2+}_{(aq)} + 2\ e^-$

$Pb_{(s)} \rightarrow Pb^{2+}_{(aq)} + 2\ e^-$

500 g

207.20 g/mol

$2(Li_{(s)} \rightarrow Li^+_{(aq)} + e^-)$

$2\ Li_{(s)} \rightarrow 2\ Li^+_{(aq)} + 2\ e^-$

6.94 g/mol

m = ?

$$m_{(Li)} = 500\ \cancel{g\ Pb} \times \frac{1\ \cancel{mol\ Pb}}{207.20\ \cancel{g\ Pb}} \times \frac{2\ \cancel{mol\ Li}}{1\ \cancel{mol\ Pb}} \times \frac{6.94\ g}{1\ \cancel{mol\ Li}}$$

$= 33.494$ g

$= 33.5$ g The mass of lithium oxidized is 33.5 g. **(3 marks)**

b. The lithium-polymer battery would be best because it would be the lightest battery and should take up the least space. It would also have the highest energy density; that is, it will deliver the most energy per unit mass. **(2 marks)**

3. a. Variables: $H = 43.7$ MJ/kg $m = 37$ kg

The students could calculate heat using the equation $q = mH$, **or**

$$q = \frac{43.7\ MJ}{1\ \cancel{kg}} \times 37\ \cancel{kg}$$

$= 1616.9$ MJ

$= 1.6 \times 10^3$ MJ The car would produce 1.6×10^3 MJ of energy from one tank of gasoline. **(2 marks)**

b. $q = 1616.9\ MJ \times 0.20$

$= 323.38$ MJ

$= 3.2 \times 10^2$ MJ It takes 3.2×10^2 MJ to move the car 700 km. **(2 marks)**

c. The students could find 90% of the answer in part b. (0.90×323.38 MJ) to get 291.04 MJ. They would then convert this number to kilojoules and divide by 1.3×10^2 kJ/kg to get the mass of batteries they need, which is 2238.8 kg. Finally, to get the number of batteries, they could divide this number by 15 kg/battery to get 149.25 batteries, rounded to 149 batteries, **or**,

Variables: $m = 15$ kg/battery $h = 323.38$ MJ

$H = 1.3 \times 10^2$ kJ/kg $\%_{eff} = 90\%$

$$x = 323.38\ \cancel{MJ} \times \frac{1000\ \cancel{kJ}}{1\ \cancel{MJ}} \times 0.90 \times \frac{1\ \cancel{kg}}{1.3 \times 10^2\ \cancel{kJ}} \times \frac{1\ battery}{15\ \cancel{kg}}$$

$= 149.25$ batteries

$= 149$ batteries The number of lead-acid batteries required is 149. **(3 marks)**

4. a.

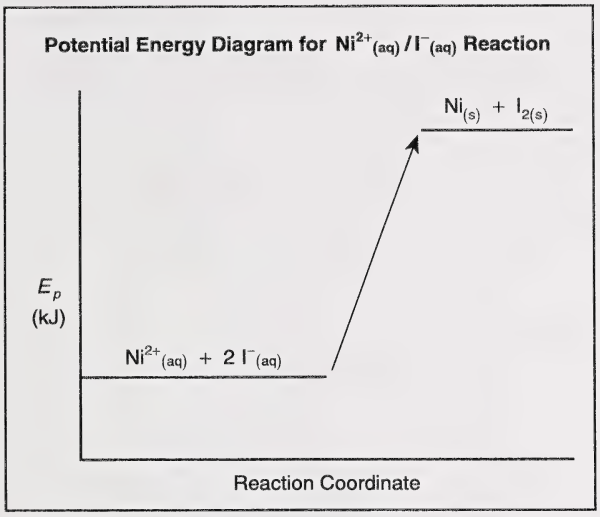
Cathode:	$Ni^{2+}_{(aq)} + 2\ e^- \rightarrow Ni_{(s)}$		$E°_r = -0.26$ V
Anode:	$2\ I^-_{(aq)} \rightarrow I_{2(s)} + 2\ e^-$		$E°_{ox} = -0.54$ V
Net Reaction:	$Ni^{2+}_{(aq)} + 2\ I^-_{(aq)} \rightarrow Ni_{(s)} + I_{2(s)}$	**(1 mark)**	$\Delta E° = -0.80$ V

b. $\Delta E° = -0.80$ V from a., **or**, $\Delta E° = E°_r(\text{cathode}) - E°_r(\text{anode})$

$= -0.26\ V - (+0.54\ V)$

$= -0.80$ V The net cell potential is -0.80 V. **(1 mark)**

c.



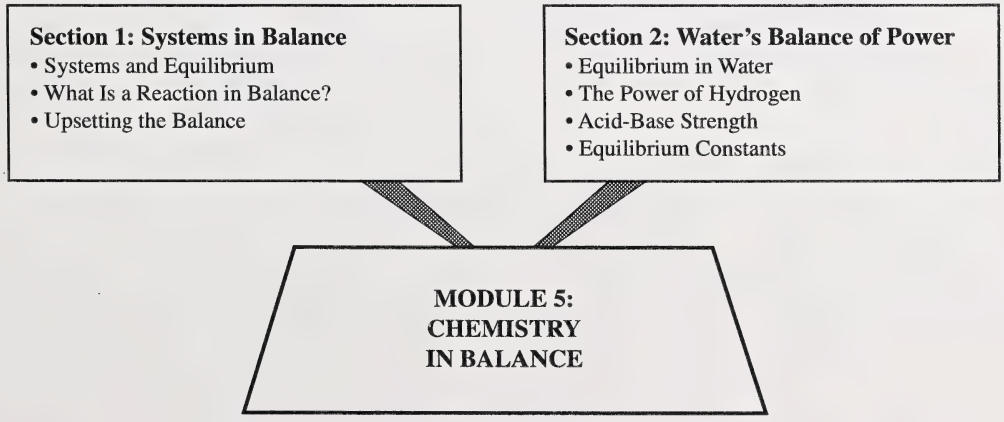
(2 marks)

Module 5: Chemistry in Balance

Overview

In this module, the student will become familiar with chemical equilibrium. Section 1 explores what constitutes a chemical equilibrium, the necessary conditions and evidence for a chemical equilibrium, ways to measure the extent of a chemical equilibrium, and factors that affect a system already at equilibrium.

Section 2 examines more specifically the equilibrium that exists in water, the presence of hydrogen $\left(H^{+}_{(aq)}\right)$ and hydroxide $\left(OH^{-}_{(aq)}\right)$ ions in water, the constant product of hydrogen and hydroxide ions $\left(K_w\right)$, the relative strengths of acids and bases, and calculations involving acid-base equilibrium constants.



Evaluation

The evaluation of this module will be based on two section assignments and one module assignment:

Section 1 Assignment	**30 marks**
Section 2 Assignment	**45 marks**
Final Module Assignment	**25 marks**
TOTAL	**100 marks**

Materials and Equipment

The following is a list of materials necessary for completing the investigations and activities in Module 5. Amounts stated represent requirements per student.

Section 1: Activity 1

Investigation: Baking Soda and Vinegar

- 2 mL baking soda (sodium bicarbonate)
- 60 mL vinegar (dilute acetic acid ≈ 1 mol/L)
- bromothymol blue
- 100 mL graduated cylinder
- measuring spoon
- thermometer
- (2) 100 mL beakers
- eyedropper

Investigation 14.1: Extent of a Chemical Reaction

The materials required for Investigation 14.1 are listed on page 428 of *Nelson Chemistry*. All solutions used, however, will be 0.10 mol/L.

- 25.0 mL of 0.10 mol/L of
  - $Na_2SO_{4(aq)}$
  - $CaCl_{2(aq)}$
- dropping bottles of 0.10 mol/L
  - $Ba(NO_3)_{2(aq)}$
  - $Na_2CO_{3(aq)}$

Section 1: Activity 3

Investigation: Equilibrium Shifts

- 3 mL cold, fresh, colourless, carbonated water (soda water)
- 2 mL limewater (saturated $Ca(OH)_{2(aq)}$)
- 3 drops bromothymol blue indicator
- eyedropper
- small syringe (5 ml-50 mL) with no needle
- solid rubber stopper with partial hole to seal syringe tip
- 13 mm × 100 mm test tube
- small beaker or container
- safety equipment

Investigation 14.3: Testing Le Châtelier's Principle

- 1 g sodium chloride, $NaCl_{(s)}$
- 2 g cobalt(II) chloride hexahydrate $\left(CoCl_2 \bullet 6H_2O_{(s)}\right)$
- 100 mL ethanol (ethyl alcohol)
- 5 mL 0.10 mol/L $AgNO_{3(aq)}$
- ice-water bath
- hot-water bath
- (2) 400 mL beakers
- 100 mL beaker
- 2 small test tubes with stoppers

Section 1: Enrichment

Investigation: K_{sp} of Calcium Hydroxide

- 20 mL of $Ca(OH)_{2(aq)}$ (saturated and filtered)
- 40 mL of 0.050 mol/L $HCl_{(aq)}$
- bromothymol blue indicator
- 10 mL pipet and bulb
- thermometer
- 250 mL Erlenmeyer flask
- titrating equipment (buret, stand, clamp)

Investigation 14.5: Studying a Chemical Equilibrium System

- 50 mL equilibrium mixture
- 2 test tubes
- 100 mL beaker
- crushed ice and hot water

> The equilibrium mixture is prepared as follows:
>
> Mix 5 mL of 0.2 mol/L $Fe(NO_3)_{3(aq)}$ with
> 5 mL of 0.2 mol/L $KSCN_{(aq)}$; dilute to 1 L final volume.

Section 2: Activity 2

Investigation 14.4: pH of Common Substances

- pH 7 buffer solution and pH meter **or** pH(hydrion) paper
- 5 mL each of various cleaning solutions such as ammonia, toilet bowl cleaner, shampoo, etc.
- 5 mL each of various foods such as pop, juices, milk, vinegar
- (3) 100 mL beakers
- 400 mL waste beaker

Final Module Assignment

Investigation: Solution Equilibria

- 2 mL saturated $Ca(OH)_{2(aq)}$ (limewater)
- 2 mL of 0.10 mol/L $NaOH_{(aq)}$
- 2 mL of 0.10 mol/L $HCl_{(aq)}$
- (2) 13 mm × 100 mm test tubes
- 2 eyedroppers
- rubber stopper for test tubes

Additional Resources

Jenkins, Frank, et al. 1993. *Nelson Chemistry.* Teacher's Ed. Scarborough, Ontario: Nelson Canada.

Kimball, Doug, E. Kuzub, and M. Sanader. 1993. *Chemistry Laboratory Manual.* Don Mills, Ontario: Addison Wesley Publishers Ltd.

Shakhashiri, B.Z. 1983. *Chemical Demonstrations: A Handbook for Teachers of Chemistry.* Vol. 1 and 2. U.S.A.: University of Wisconsin Press.

Zumdahl, Steven S. 1990. *Chemistry.* 2d ed. Toronto, Ontario: D.C. Heath and Co.

Possible Media

Videos

Chemical Equilibrium. (1984) TV Ontario. (ACCESS Network)
Includes the segments Unsteady Steadiness (equilibrium conditions), Dynamic Equilibrium, Reaction Kinetics, Reaction Tendencies (Le Châtelier's principle), The Equilibrium Constant, and The Haber Process.

Chemical Equilibrium. (1988) Classroom Video, Unit C, 9005 – Centaurus Circle, Burnaby, B.C., V3J 7N4.
Includes visual demonstrations of some systems (nitrogen dioxide/dinitrogen tetraoxide) which you may not be able to demonstrate. Some teacher notes are included.

Laser Videodisc

Cosmic Chemistry. (1992) Optical Data Corporation, New Jersey. Distributed through Perceptix Inc. (1-800-267-7788).

Section 1: Systems in Balance

Key Concepts

In this section the student will study some chemical systems which exhibit properties of equilibrium and determine the factors which indicate a system is at equilibrium (constant macroscopic properties, steady state). Students will also learn and apply the mathematical models of percent reaction and the equilibrium constant, and use Le Châtelier's principle to predict how a system will recover when put under specific stresses.

Teaching Suggestions

- An easy demonstration to illustrate equilibrium is to set up two equal glass aquaria – A and B – with different amounts of water (one container is almost empty). Give two students one beaker (same size) each and have each student start emptying his or her respective aquarium into the other at the same rate (as one student empties a beaker into Aquarium A, the other student is emptying a beaker into Aquarium B).

  Eventually the water heights of the aquaria will be such that each student is transferring exactly the same amount of water.

  Introduce new conditions by restarting the demonstration. Have one aquarium with no water initially or change the sizes of the beakers.

- You can make visual aids to illustrate the interrelationships between percent reaction, equilibrium constant, and amounts of reactants and products (see the graphics in the module).

- Many demonstrations involving the colour changes of solutions (e.g., the $FeSCN^{2+}$ system, page 432 in *Nelson Chemistry*) can be done on the overhead to obtain a qualitative understanding of Le Châtelier's principle.

- The textbook deals only with homogeneous systems (i.e., gases or aqueous systems). You might want to introduce heterogeneous systems (solids or liquids are brought into the system). Ask questions such as

  – Does the amount of water in a closed container make any difference to the equilibrium vapour pressure at a particular temperature?

  – Would liquid water be included in the equilibrium law?

Section 1: Assignment Answer Key (30 marks)

Multiple Choice

1. C 2. B 3. D 4. D 5. A **(5 marks)**

Written Response

6. a. The pressure was increased.

   b. Some $CO_{2(g)}$ was removed from the system.

   c. The temperature was increased.

   d. A catalyst (or inert gas) was added to the system. **(4 marks)**

7. $$K = \frac{\left[PCl_{3(g)}\right]\left[Cl_{2(g)}\right]}{\left[PCl_{5(g)}\right]}$$
$$= \frac{(0.850\ \text{mol/L})(0.850\ \text{mol/L})}{(0.406\ \text{mol/L})}$$
$$= 1.78$$
The equilibrium constant is 1.78. **(2 marks)**

8. The system cannot be at equilibrium because the colour is still changing. At equilibrium, all macroscopic characteristics stay constant. **(2 marks)**

9. The temperature in Reaction 2 was lower. Since the ΔH of the reaction is negative, the reaction is exothermic. At the new temperature, the K increased, meaning the products were favoured. A lower temperature favours the exothermic reaction which is the forward reaction in this case. **(3 marks)**

10. a. $$K = \frac{\left[NO_{2(g)}\right]^2}{\left[NO_{(g)}\right]^2\left[O_{2(g)}\right]}$$
$$= \frac{\left(1.50\times10^{-1}\ \text{mol/L}\right)^2}{\left(2.50\times10^{-2}\ \text{mol/L}\right)^2\left(5.58\times10^{-8}\ \text{mol/L}\right)}$$
$$= 6.4516\times10^{8}\ \text{mol/L}$$
$$= 6.45\times10^{8}$$ **(2 marks)**

   b. i. $$\left[O_{2(g)}\right] = \frac{\left[NO_{2(g)}\right]^2}{\left[NO_{(g)}\right]^2 K}$$
$$\left[O_{2(g)}\right] = \frac{\left(2.00\times10^{-1}\ \text{mol/L}\right)^2}{\left(1.50\times10^{-2}\ \text{mol/L}\right)^2\left(6.4516\times10^{8}\ \text{mol/L}\right)}$$
$$= 2.76\times10^{-7}\ \text{mol/L}$$ **(1 mark)**

   ii. $$\left[NO_{(g)}\right] = \sqrt{\frac{\left[NO_{2(g)}\right]^2}{\left[O_{2(g)}\right]K}}$$
$$= \sqrt{\frac{\left(7.50\times10^{-2}\ \text{mol/L}\right)^2}{\left(3.00\times10^{-3}\ \text{mol/L}\right)\left(6.4516\times10^{8}\ \text{mol/L}\right)}}$$
$$= 5.39\times10^{-5}\ \text{mol/L}$$ **(1 mark)**

iii. $\left[NO_{2(g)}\right] = \sqrt{K \times \left[NO_{(g)}\right]^2 \left[O_{2(g)}\right]}$

$= \sqrt{\left(6.4516 \times 10^{8}\ \text{mol/L}\right)\left(2.00 \times 10^{-4}\ \text{mol/L}\right)^2 \left(1.00 \times 10^{-5}\ \text{mol/L}\right)}$

$= 1.61 \times 10^{-2}\ \text{mol/L}$ **(1 mark)**

11. a. The number of moles of $N_2O_{4(g)}$ used up was 0.24 mol (0.40 mol − 0.16 mol = 0.24 mol). **(1 mark)**

b. One mole of $N_2O_{4(g)}$ produces two moles of $NO_{2(g)}$.

Therefore, 2×0.24 mol = 0.48 mol of $NO_{2(g)}$ were produced.

$\left[NO_{2(g)}\right] = \dfrac{0.48\ \text{mol}}{1.0\ \text{L}}$

$= 0.48\ \text{mol/L}$

The concentration of $NO_{2(g)}$ is 0.48 mol/L. **(2 marks)**

c. $K = \dfrac{\left[NO_{2(g)}\right]^2}{\left[N_2O_{4(g)}\right]}$ **(1 mark)**

d. $K = \dfrac{(0.48\ \text{mol/L})^2}{(0.16\ \text{mol/L})}$

$= 1.4$

The equilibrium constant is 1.4. **(1 mark)**

e. You would observe the colour to remain constant when equilibrium was reached. **(1 mark)**

12. The analysis could be written as follows:

The radioactive material was originally in the solid form, and was then found in the filtrate. Since the filtrate can only contain ions, some of the radioactive solid must have dissolved in spite of the solution being saturated. The system must be undergoing a dynamic process since the amount of solid at the bottom of the test tube did not change. **(3 marks)**

Section 2: Water's Balance of Power

Key Concepts

In this section the student will apply the concepts of equilibrium and Le Châtelier's principle introduced in Section 1. The water equilibrium is studied and the inverse proportionality of $\left[H^+_{(aq)}\right]$ and $\left[OH^-_{(aq)}\right]$ is established with respect to K_w. Acid-base concepts are revisited and expanded on by looking at the equilibrium that weak acids participate in; pH and pOH calculations are covered. Percent ionization and K_a are utilized to indicate the extent of a reaction as well as to calculate $\left[H^+_{(aq)}\right]$, $\left[OH^-_{(aq)}\right]$, pH, and pOH.

Teaching Suggestions

You will have to ensure the students can use their calculators in the correct manner. You should find many more questions for students to practise, going back and forth between mass, concentration, pH, pOH, $\left[H^+_{(aq)}\right]$, $\left[OH^-_{(aq)}\right]$, K_w, and K_a. Emphasize calculator skills to try and make the students work faster and more accurately. Significant digits are important, and the rules change for pH and pOH values.

Section 2: Assignment Answer Key (45 marks)

Multiple Choice

1. B 2. B 3. C 4. D 5. A **(5 marks)**

Written Response

6. a. $C_6H_5COOH_{(aq)} \rightleftarrows H^+_{(aq)} + C_6H_5COO^-_{(aq)}$ **(1 mark)**

b.
$$K_a = \frac{\left[H^+_{(aq)}\right]\left[C_6H_5COO^-_{(aq)}\right]}{\left[C_6H_5COOH_{(aq)}\right]}$$
$$= \frac{\left[H^+_{(aq)}\right]^2}{\left[C_6H_5COOH_{(aq)}\right]}$$

$$\left[H^+_{(aq)}\right] = \sqrt{(K_a)[\text{acid}]}$$
$$= \sqrt{(6.3\times10^{-5}\ \text{mol/L})(0.0150\ \text{mol/L})}$$
$$= 9.7211\times10^{-4}\ \text{mol/L}$$
$$= 9.72\times10^{-4}\ \text{mol/L}$$

$$\text{pH} = -\log\left[H^+_{(aq)}\right]$$
$$= -\log\left(9.7211\times10^{-4}\right)$$
$$= 3.01$$

The pH is 3.01. **(3 marks)**

7 a.
$$\left[H^+_{(aq)}\right] = 10^{-\text{pH}}$$
$$= 10^{-2.435}$$
$$= 3.6728\times10^{-3}\ \text{mol/L}$$
$$= 3.67\times10^{-3}\ \text{mol/L}$$

$$K_a = \frac{\left[H^+_{(aq)}\right]^2}{[\text{acid}]}$$
$$[\text{acid}] = \frac{\left[H^+_{(aq)}\right]^2}{K_a}$$
$$= \frac{\left(3.6728\times10^{-3}\ \text{mol/L}\right)^2}{1.8\times10^{-5}\ \text{mol/L}}$$
$$= 0.749\,42\ \text{mol/L}$$
$$= 0.749\ \text{mol/L}$$

The [vinegar] is 0.749 mol/L. **(3 marks)**

b.
$$m_{(CH_3COOH)} = 0.100\ \cancel{L} \times \frac{0.749\,42\ \cancel{\text{mol}}}{\cancel{L}} \times \frac{60.06\ \text{g}}{1\ \cancel{\text{mol}}}$$
$$= 4.5010\ \text{g}$$
$$= 4.50\ \text{g}$$

The mass of acetic acid (vinegar – $CH_3COOH_{(aq)}$) in 100 mL is 4.50 g. **(3 marks)**

c.
$$\%\ \text{error} = \frac{|\ \text{experimental value} - \text{predicted value}\ |}{|\ \text{predicted value}\ |} \times 100\%$$
$$= \frac{|\ 4.50\ \text{g} - 5.0\ \text{g}\ |}{|\ 5.0\ \text{g}\ |} \times 100\%$$
$$= 10\%$$

The percent error is 10%. **(1 mark)**

8. The experimental percent ionization is calculated as follows:

$$\left[HF_{(aq)}\right] = 8.0\ \cancel{g\ HF} \times \frac{1\ \text{mol HF}}{20.01\ \cancel{g\ HF}} \times \frac{1}{2.00\ \text{L}}$$
$$= 0.199\ 90\ \text{mol/L HF}$$
$$= 0.20\ \text{mol/L HF}$$

$$\left[H^+_{(aq)}\right] = 10^{-pH}$$
$$= 10^{-2.080}$$
$$= 8.3176 \times 10^{-3}\ \text{mol/L}$$
$$= 8.32 \times 10^{-3}\ \text{mol/L}$$

$$\%\ \text{ionization} = \frac{\left[H^+_{(aq)}\right]}{[\text{acid}]} \times 100$$
$$= \frac{8.3176 \times 10^{-3}\ \text{mol/L}}{0.199\ 90\ \text{mol/L}} \times 100$$
$$= 4.16\%$$

The percent ionization of $HF_{(aq)}$ is 4.16%. **(3 marks)**

9. $$\left[H^+_{(aq)}\right] = 10^{-pH}$$
$$= 10^{-2.456}$$
$$= 3.4995 \times 10^{-3}\ \text{mol/L}$$
$$= 3.50 \times 10^{-3}\ \text{mol/L}$$

$$[\text{acid}] = \frac{\left[H^+_{(aq)}\right]^2}{K_a}$$
$$= \frac{\left(3.4995 \times 10^{-3}\ \text{mol/L}\right)^2}{1.8 \times 10^{-4}\ \text{mol/L}}$$
$$= 6.8034 \times 10^{-2}\ \text{mol/L}$$
$$= 6.80 \times 10^{-2}\ \text{mol/L}$$

$$m_{(HCOOH)} = \frac{6.8034 \times 10^{-2}\ \cancel{\text{mol HCOOH}}}{\cancel{L}} \times 1.0 \times 10^{-5}\ \text{m}\cancel{L} \times \frac{46.03\ \text{g}}{1\ \cancel{\text{mol HCOOH}}}$$
$$= 3.13 \times 10^{-5}\ \text{mg}$$

The ant uses 3.13×10^{-5} mg of formic acid in each bite. **(4 marks)**

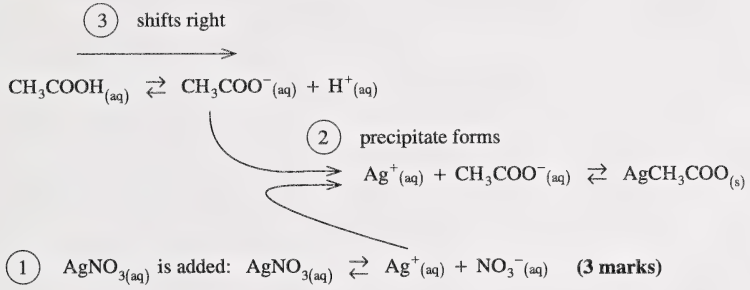
10.

$\left[H^+_{(aq)}\right]$	$\left[OH^-_{(aq)}\right]$	pH	pOH	Acid, Base, or Neutral
2.5×10^{-5}	4.0×10^{-10}	4.60	9.40	acid
1×10^{-4}	8×10^{-11}	3.9	10.1	acid
5×10^{-12}	2×10^{-3}	11.3	2.7	base
2.9×10^{-11}	3.5×10^{-4}	10.54	3.46	base
1×10^{-7}	1×10^{-7}	7.0	7.0	neutral

(10 marks)

11. a. The prediction may be as follows:

Since $Ag^+_{(aq)}$ and $CH_3COO^-_{(aq)}$ are mutually insoluble, the addition of $AgNO_{3(aq)}$ will remove acetate ions from the acetic acid equilibrium. By Le Châtelier's principle, the system will shift to the right to increase the acetate ion concentration. This produces more $H^+_{(aq)}$ ions, thereby causing the pH to decrease.


3 shifts right
$CH_3COOH_{(aq)} \rightleftarrows CH_3COO^-_{(aq)} + H^+_{(aq)}$
2 precipitate forms
$Ag^+_{(aq)} + CH_3COO^-_{(aq)} \rightleftarrows AgCH_3COO_{(s)}$
1 $AgNO_{3(aq)}$ is added: $AgNO_{3(aq)} \rightleftarrows Ag^+_{(aq)} + NO_3^-_{(aq)}$

(3 marks)

b. The pH of the acetic acid solution is calculated as follows:

$$CH_3COOH_{(aq)} \rightleftarrows CH_3COO^-_{(aq)} + H^+_{(aq)}$$

$$K_a = \frac{\left[CH_3COO^-_{(aq)}\right]\left[H^+_{(aq)}\right]}{\left[CH_3COOH_{(aq)}\right]} = \frac{\left[H^+_{(aq)}\right]^2}{\left[CH_3COOH_{(aq)}\right]}$$

$$\left[H^+_{(aq)}\right] = \sqrt{K_a\left[CH_3COOH_{(aq)}\right]} = \sqrt{\left(1.8\times10^{-5}\ \text{mol/L}\right)\left(8.3\times10^{-3}\ \text{mol/L}\right)}$$
$$= 3.865\times10^{-4}\ \text{mol/L}$$
$$= 3.9\times10^{-4}\ \text{mol/L}$$

$$\text{pH} = -\log\left[H^+_{(aq)}\right] = -\log\left(3.865\times10^{-4}\right) = 3.41$$

The pH should be 3.41. **(3 marks)**

c. The experimental design may be as follows:

$AgNO_{3(aq)}$ is added to a sample of acetic acid. The pH of the acetic acid solution is measured and recorded before and after the addition of $AgNO_{3(aq)}$. Three trials are performed for consistency of results. The temperature and size of each acetic acid sample and the amount of $AgNO_{3(aq)}$ added are kept constant. **(3 marks)**

d. The procedure may be as follows:

- Place 10 mL of the acetic acid solution in a small test tube or beaker.
- Measure the pH of the acetic acid solution with a pH meter or pH paper.
- Measure the temperature of the solution.

- Add 10 drops of $AgNO_{3(aq)}$ to the acetic acid solution. Record your observations.
- Measure the pH of the solution.
- Continue to add the $AgNO_{3(aq)}$ drop by drop until a noticeable change in pH has occurred.
- Record the number of drops of $AgNO_{3(aq)}$ added.
- Record the final pH and temperature of the solution.
- Repeat the procedure twice for consistent results. **(3 marks)**

Final Module Assignment Answer Key (25 marks)

1. a. $K = \dfrac{\left[CO_{(g)}\right]\left[Cl_{2(g)}\right]}{\left[COCl_{2(g)}\right]}$ **(1 mark)**

b. $K = \dfrac{(0.0060\ \text{mol/L})^2}{(0.0440\ \text{mol/L})}$

$= 8.182 \times 10^{-4}\ \text{mol/L}$

$= 8.2 \times 10^{-4}\ \text{mol/L}$ The K value for the system is $8.2 \times 10^{-4}\ \text{mol/L}$.

Trial ii: $\left[Cl_{2(g)}\right] = \dfrac{K\left[COCl_{2(g)}\right]}{\left[CO_{(g)}\right]}$

$= \dfrac{\left(8.182 \times 10^{-4}\ \text{mol/L}\right)(0.750\ \text{mol/L})}{(0.0040\ \text{mol/L})}$

$= 0.1534\ \text{mol/L}$

$= 0.15\ \text{mol/L}$

Trial iii: $\left[COCl_{2(g)}\right] = \dfrac{\left[CO_{(g)}\right]\left[Cl_{2(g)}\right]}{K}$

$= \dfrac{(0.025\ \text{mol/L})(0.000\,15\ \text{mol/L})}{\left(8.182 \times 10^{-4}\ \text{mol/L}\right)}$

$= 4.583 \times 10^{-3}\ \text{mol/L}$

$= 4.6 \times 10^{-3}\ \text{mol/L}$ **(3 marks)**

c. $COCl_{2(g)} \rightleftarrows CO_{(g)} + Cl_{2(g)}$

$1(-218.8) \quad 1(-110.5) \quad 1(0)$

$\Delta H°_r = \sum nH°_{fp} - \sum nH°_{fr}$

$= \left(1\ \text{mol} \times \dfrac{-110.5\ \text{kJ}}{\text{mol}} + 1\ \text{mol} \times \dfrac{0\ \text{kJ}}{\text{mol}}\right) - \left(1\ \text{mol} \times \dfrac{-218.8\ \text{kJ}}{\text{mol}}\right)$

$= +108.3\ \text{kJ}$

The $\Delta H°_r$ for the phosgene gas reaction is $+108.3$ kJ. **(2 marks)**

d. The K value would get larger. An increase in temperature favours the direction that uses up energy. Since this reaction is endothermic, the forward reaction is favoured, giving more products and less reactants, hence a larger K value. **(1 mark)**

e. The equilibrium would shift to the left (reactants). This would leave a smaller number of molecules and reduce the pressure that was initially increased by the change in volume. **(1 mark)**

f. Yes, the $COCl_{2(g)}$ sample will contain some of the radioactive ^{14}C. Even though the system is at equilibrium and no observable changes are taking place, both the forward and reverse reactions are taking place at the same rate and thus some of the $CO_{(g)}$ that has been labelled with ^{14}C will combine with $Cl_{2(g)}$ to form phosgene. An equilibrium is a dynamic situation. **(2 marks)**

2. a. $[H^+_{(aq)}] = 10^{-pH}$

$= 10^{-2.156}$

$= 6.9823 \times 10^{-3}$ mol/L

$= 6.98 \times 10^{-3}$ mol/L

The $[H^+_{(aq)}]$ of the unknown acid is 6.98×10^{-3} mol/L. **(1 mark)**

b. $[\text{acid}] = 45.14 \cancel{mL} \times \dfrac{0.150 \cancel{\text{mol NaOH}}}{1 \cancel{L}} \times \dfrac{1 \text{ mol } \cancel{\text{acid}}}{1 \cancel{\text{mol NaOH}}} \times \dfrac{1}{25.00 \cancel{mL} \cancel{\text{acid}}}$

$= 0.270\ 84$ mol/L

$= 0.271$ mol/L

The concentration of the acid is 0.271 mol/L. **(2 marks)**

c. $K_a = \dfrac{[H^+_{(aq)}]^2}{[\text{acid}]}$

$= \dfrac{(6.9823 \times 10^{-3} \text{ mol/L})^2}{(0.270\ 84 \text{ mol/L})}$

$= 1.80 \times 10^{-4}$ mol/L

The K_a of the acid is 1.80×10^{-4} mol/L. **(1 mark)**

d. The calculated K_a is the same as the K_a of methanoic acid, $HCOOH_{(aq)}$; therefore, the acid is possibly methanoic acid. **(1 mark)**

3. a. The changes to the limewater equilibrium are predicted as follows:

$$Ca(OH)_{2(aq)} \rightleftarrows Ca^{2+}_{(aq)} + 2\ OH^-_{(aq)}$$

limewater

- When $NaOH_{(s)}$ is added to the limewater solution, the equilibrium will shift to the left, causing some $Ca(OH)_{2(s)}$ (precipitate) to form.
- When $HCl_{(aq)}$ is then added to the solution, the $HCl_{(aq)}$ will react with the $OH^-_{(aq)}$ ions in solution, shifting the limewater equilibrium to the right and causing the $Ca(OH)_{2(s)}$ to redissolve. **(3 marks)**

b. Your evidence should be similar to the following:

Imposed Changes	$Ca(OH)_{2(aq)}$ Solution Evidence
Initial Solution	• The initial solution was clear and colourless.
Addition of $NaOH_{(aq)}$	• A milky white precipitate became visible after the addition of 2 drops of $NaOH_{(aq)}$. • The white precipitate was very visible after the addition of 10 drops of $NaOH_{(aq)}$.
Addition of $HCl_{(aq)}$	• Where the drops of $HCl_{(aq)}$ hit the solution, the precipitate disappeared. • As drops of $HCl_{(aq)}$ were added, the precipitate gradually disappeared. • After 10 drops of $HCl_{(aq)}$ were added, the solution was completely clear and colourless.

(3 marks)

c. The analysis is as follows:

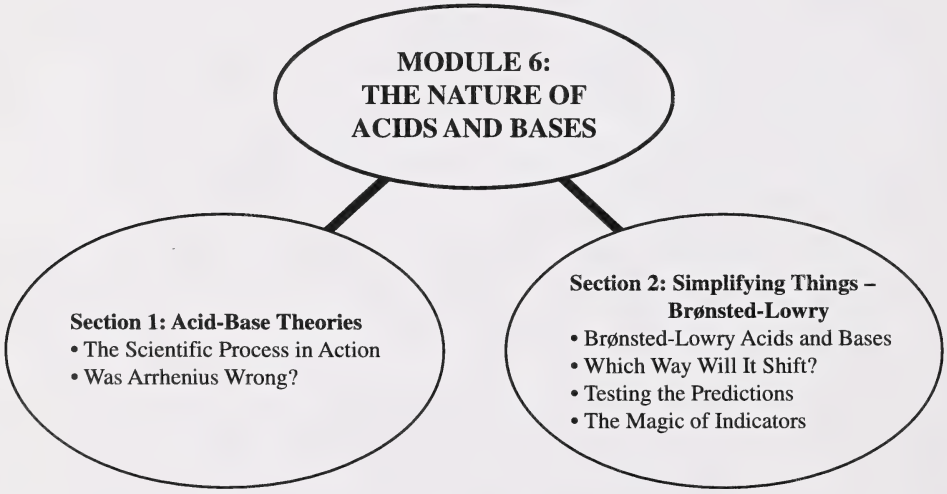
- Both predictions involving the changes occurring when the limewater equilibrium was upset were confirmed.
- The results suggest that more than one equilibrium is occurring in the solution. In addition to the limewater equilibrium, the following equilibrium is taking place: $H^+_{(aq)} + OH^-_{(aq)} \rightleftarrows H_2O_{(l)}$. This equilibrium appears to strongly favour products since the precipitate cleared completely and quickly. **(2 marks)**

d. The procedure is judged to be adequate since all steps were performed easily and consistent results were obtained. Le Châtelier's principle is supported by the investigation since the predictions were confirmed by the results. (The testing of further equilibria would have further helped to confirm Le Châtelier's principle.) **(2 marks)**

Module 6: The Nature of Acids and Bases

Overview

This module uses science process as a major developmental theme to gradually introduce students to a number of theoretical definitions of acids and bases. Students learn that acid-base theories have evolved by the continuous revision of scientific ideas. There is much discussion about the advantages and limitations of succeeding theories. This culminates in a detailed discussion of the Brønsted-Lowry definition of acids and bases which in turn becomes the foundation for an understanding of the behaviour of indicators and acid-base equilibria.


MODULE 6:
THE NATURE OF
ACIDS AND BASES
Section 1: Acid-Base Theories
• The Scientific Process in Action
• Was Arrhenius Wrong?
Section 2: Simplifying Things –
Brønsted-Lowry
• Brønsted-Lowry Acids and Bases
• Which Way Will It Shift?
• Testing the Predictions
• The Magic of Indicators

Evaluation

The evaluation of this module will be based on two section assignments and one module assignment:

Section 1 Assignment	**25 marks**
Section 2 Assignment	**40 marks**
Final Module Assignment	**35 marks**
TOTAL	**100 marks**

Materials and Equipment

The following is a list of materials necessary for completing the investigations and activities in Module 6. Amounts stated represent requirements per student.

Section 1: Activity 1

Investigation 15.1: Testing Arrhenius's Acid-Base Definitions

- 1 mL of 0.10 mol/L solutions of
  - hydrochloric acid $\left(HCl_{(aq)}\right)$
  - sodium carbonate $\left(Na_2CO_{3(aq)}\right)$
  - sodium hydroxide $\left(NaOH_{(aq)}\right)$
  - acetic acid (vinegar) $\left(CH_3COOH_{(aq)}\right)$
  - sodium hydrogen carbonate $\left(NaHCO_{3(aq)}\right)$
  - sodium hydrogen sulphate $\left(NaHSO_{4(aq)}\right)$
  - ammonia $\left(NH_{3(aq)}\right)$
- saturated solutions of
  - calcium hydroxide $\left(Ca(OH)_{2(aq)}\right)$
  - magnesium oxide $\left(MgO_{(aq)}\right)$
- 1 mL of carbonated water $\left(CO_{2(aq)}\right)$
- 10 strips blue litmus paper
- 10 strips red litmus paper
- spot plate
- conductivity apparatus
- dropper bottles
- safety glasses
- lab aprons

Section 2: Activity 3

Investigation 15.2: Testing Brønsted-Lowry Predictions

- 20.0 mL of 0.10 mol/L
  - $NH_4Cl_{(aq)}$
  - $HCl_{(aq)}$
  - $NaHSO_{4(aq)}$
- 10.0 mL of 0.10 mol/L
  - $NaC_6H_5COO_{(aq)}$
  - $NaOH_{(aq)}$
  - $NaCH_3COO_{(aq)}$
- 0.10 grams each of the following
  - $NaCl_{(s)}$
  - $Na_3PO_4 \bullet 12H_2O_{(s)}$
  - $Al_2(SO_4)_3 \bullet 14H_2O_{(s)}$
  - $NaHCO_{3(aq)}$
- (2) 13 mm × 100 mm test tubes
- wash bottle of distilled water
- 10 strips blue litmus paper
- 10 strips red litmus paper
- roll of pHydrion paper (pH 2-12)
- 50 mL beaker
- scoopula
- safety glasses
- lab aprons
- pH meter (optional)

Additional Resources

Shapiro, B., & S. Shapiro. 1989. *Chemistry at Work*. Mississauga, Ontario: Copp Clark Pitman Ltd.

Zumdahl, Steven S. 1990. *Chemistry*. 2d ed. Lexington, Massachusetts: D.C. Heath and Company.

Possible Media

Video

CHEM Study Series. (1989) Ward's Natural Science Ltd., St. Catherines, Ontario.
Includes the segment Acid-Base Indicators, 2d ed.

Section 1: Acid-Base Theories

Key Concepts

Section 1 traces the history of the development of acid-base theory from the earliest concepts to a detailed discussion of the modified Arrhenius theory. The emphasis is on science process throughout. The strengths and limitations of each theory are discussed in turn, emphasizing how each successive attempt broadens and enhances the ability to both explain and predict acid-base behaviour. Section 1 concludes with a discussion of the role of water in acid-base theory. Water's involvement in the formation of the hydronium ion and its effectiveness on the ability to explain acid-base behaviour foreshadows the Brønsted-Lowry theory which is discussed in Section 2.

Teaching Suggestions

Investigation 15.1 can be run most safely with the least waste of materials if the following guidelines are followed:

- The instructor demonstrates the conductivity test and the class records group data, **or**

  One set of 50 mL beakers containing approximately 20 mL of each solution is set up so that each student or lab group can use the same set by rotating through in turn to obtain their individual conductivity data.

- Investigation 15.1 is ideal for spot plates and dropper bottles set up at separate stations for the litmus tests. Spot plates minimize the quantities of solution required for each test.

Section 1: Assignment Answer Key (25 marks)

Part A: Multiple Choice

1. D 2. B 3. C 4. D 5. A 6. C 7. B 8. A **(8 marks)**

Part B: Written Response

9.

Substance	Lavoisier Theory	Davy/Liebig Theory	Arrhenius Theory	Revised Theory
HCl		acid	acid	acid
NH_3	neutral	acid	neutral	base
KOH			base	base
$NaHCO_3$			neutral	base
NO_2	acid	neutral	neutral	acid
CaO	acid		neutral	base

(9 marks)

10. Limitations of the Arrhenius theory include the following:

- The effectiveness of the theory is limited to aqueous solutions.
- The Arrhenius theory cannot explain or predict the properties of many common substances. **(2 marks)**

11. a. $CO_{2(g)} + H_2O_{(l)} \rightleftarrows H_2CO_{3(aq)}$

$H_2CO_{3(aq)} + H_2O_{(l)} \rightleftarrows H_3O^+_{(aq)} + HCO_3^-{}_{(aq)}$ **(1 mark)**

b. $HCN_{(aq)} + H_2O_{(l)} \rightleftarrows H_3O^+_{(aq)} + CN^-_{(aq)}$ **(1 mark)**

c. $O^{2-}_{(aq)} + H_2O_{(l)} \rightleftarrows OH^-_{(aq)} + OH^-_{(aq)}$ **(1 mark)**

12. The student should mention points such as the following:

- Knowledge has been obtained in a series of logical steps based on the precepts of science process.
- The growth of acid-base knowledge has been incremental, like building a house stone by stone.
- Society presently has a coherent body of acid-base knowledge based on and verified by predictive theories. **(3 marks)**

Section 2: Simplifying Things – Brønsted-Lowry

Key Concepts

In Section 2, students learn the details of the Brønsted-Lowry theory of acids and bases. Though the details all interconnect, there are many facets to the theory, so Activity 1 takes students onc step at a time through each of the ideas of the theory, and then puts all the pieces together in the last step.

In Activities 2 and 3, two useful empirical generalizations are added to the Brønsted-Lowry theory to enhance its predictive power. These form the foundation for the so-called five-step method of analysing Brønsted-Lowry systems. At this point, several lab exercises and an investigation are done to test the ability of the Brønsted-Lowry theory to predict the products and the extent of the reaction equilibrium for a number of acid-base reactions. The theory emerges less than perfect, but is deemed sufficiently good to be used as a tool for understanding the behaviour of acid-base indicators (Activity 4).

Activity 4 investigates the empirical and theoretical definitions of acid-base indicators. Indicators emerge as good examples of Brønsted-Lowry conjugate acid-base pairs that are unique in that they announce the fact that they are donating a proton by changing colours. This activity concludes with a problem-solving exercise in which students analyse data to determine the pH of unknown solutions. A solid understanding of indicators must be carried into Module 7.

Teaching Suggestions

- The following suggestions may prove helpful for Investigation 15.2:
  - Exact quantities and precision measurements are not needed here. In the first four reactions, 5.0 mL of 0.10 mol/L solutions should be sufficient to detect an odour if there is one.
  - In Reactions 5-8, a minute quantity of solid dissolved in 1 mL of water on a spot plate will suffice. All you need is enough solution to wet the tip of the litmus paper and read the results.
  - In Reactions 9-11, all you need to know is if the pH went up or down. The actual pH value is not important, so a pH meter is not really necessary.
  - The toughest part of the investigation from the student's point of view is coming up with a suitable data table to keep track of all the evidence they will be obtaining.
- It is important to emphasize to students how the Brønsted-Lowry theory is a good example for illustrating the nature of science and scientific inquiry.

Section 2: Assignment Answer Key (40 marks)

Part A: Multiple Choice

1.	B	3.	B	5.	C	7.	D	9.	A	11.	C **(11 marks)**
2.	B	4.	C	6.	A	8.	B	10.	C		

Part B: Written Response

12. a. $CH_3COO^-_{(aq)} + NH_4^+_{(aq)} \overset{<50\%}{\rightleftarrows} CH_3COOH_{(aq)} + NH_{3(aq)}$ **(2 marks)**

(favours reactants)

b. $HPO_4^{2-}_{(aq)} + CH_3COOH_{(aq)} \overset{>50\%}{\rightleftarrows} H_2PO_4^-_{(aq)} + CH_3COO^-_{(aq)}$ **(2 marks)**

(favours products)

c. $H_3O^+_{(aq)} + NH_{3(aq)} \overset{>50\%}{\rightleftarrows} NH_4^+_{(aq)} + H_2O_{(l)}$ **(2 marks)**

(favours products)

13. The order, from weakest to strongest, of the acids is $HD_{(aq)}$, $HB_{(aq)}$, $HA_{(aq)}$, $HC_{(aq)}$. **(4 marks)**

14. $pOH = -\log(10^{-1})$
$= 1$

$pOH = -\log(10^{-3})$
$= 3$

If the pOH changes from 1 to 3, then the pH changes from 13 to 11. At pH = 13, indigo carmine is yellow. At pH = 11, indigo carmine is blue. Therefore, indigo carmine will change from yellow to blue. **(2 marks)**

15. a. xii c. vi e. ix or v g. i i. xiii **(9 marks)**

b. vii d. iii f. ii h. iv

16. a. Equation 1 (hydrogen sulphate ion with perchloric acid):

$HSO_3^-_{(aq)} + H_3O^+_{(aq)} \rightleftarrows H_2SO_{3(aq)} + H_2O_{(l)}$ **(2 marks)**
base acid acid base

Equation 2 (hydrogen sulphate ion with dihydrogen borate ion):

$HSO_3^-_{(aq)} + H_2BO_3^-_{(aq)} \rightleftarrows H_3BO_{3(aq)} + SO_3^{2-}_{(aq)}$ **(2 marks)**
acid base acid base

b. Equation 1:

$HSO_3^-_{(aq)} - H_2SO_{3(aq)}$ and $H_3O^+_{(aq)} - H_2O_{(l)}$

Equation 2:

$HSO_3^-_{(aq)} - SO_3^{2-}_{(aq)}$ and $H_2BO_3^-_{(aq)} - H_3BO_{3(aq)}$ **(2 marks)**

c. Equation 1: **Products** are favoured.

Equation 2: **Reactants** are favoured. **(2 marks)**

Final Module Assignment Answer Key (35 marks)

Part A: Multiple Choice

1.	B	3.	A	5.	C	7.	B
2.	D	4.	B	6.	D	8.	B **(8 marks)**

Part B: Numerical Response

9. | 1 | 4 | 6 | 5 | **(1 mark)**

10. | 2 | 4 | 3 | 1 | **(1 mark)**

Part C: Written Response

11. a. $\underset{\text{—}}{Na^+_{(aq)}}$, $\underset{\textbf{SB}}{\textbf{A}}\ H_2PO_4^-{}_{(aq)}$, $\underset{\text{—}}{K^+_{(aq)}}$, $\underset{\textbf{B}}{\textbf{SA}}\ HOOCCOO^-_{(aq)}$, $\underset{\textbf{B}}{\textbf{A}}\ H_2O_{(l)}$

$H_2PO_4^-{}_{(aq)} + HOOCCOO^-_{(aq)} \overset{<50\%}{\rightleftarrows} H_3PO_{4(aq)} + OOCCOO^{2-}{}_{(aq)}$ **(2 marks)**

(reactants are favoured)

b. $\underset{\textbf{B}}{\textbf{SA}}\ H_3O^+_{(aq)}$, $I^-_{(aq)}$, $\underset{\text{—}}{Na^+_{(aq)}}$, $\underset{\textbf{SB}}{CN^-_{(aq)}}$, $\underset{\textbf{B}}{\textbf{A}}\ H_2O_{(l)}$

$H_3O^+_{(aq)} + CN^-_{(aq)} \overset{>50\%}{\rightleftarrows} HCN_{(aq)} + H_2O_{(l)}$ **(2 marks)**

(products are favoured)

c. $\underset{\textbf{B}}{\textbf{SA}}\ HBb_{(aq)}$, $\underset{\text{—}}{Li^+_{(aq)}}$, $\underset{\textbf{SB}}{\textbf{A}}\ HCO_3^-{}_{(aq)}$, $\underset{\textbf{B}}{\textbf{A}}\ H_2O_{(l)}$

$HBb_{(aq)} + HCO_3^-{}_{(aq)} \overset{>50\%}{\rightleftarrows} H_2CO_{3(aq)} + Bb^-_{(aq)}$ **(2 marks)**

(products are favoured)

12. The solution in 11.c. will be blue. Since the products are favoured, the indicator will be in its base form, which is blue. **(1 mark)**

13. a. The three acids, listed in order from strongest to weakest, are $HC_{(aq)}$, $HA_{(aq)}$, $HD_{(aq)}$. **(1 mark)**

b. The species that would be the weakest conjugate base is $C^-_{(aq)}$. **(1 mark)**

14. a. $CH_3COO^-_{(aq)} + H_2O_{(l)} \rightleftarrows CH_3COOH_{(aq)} + OH^-_{(aq)}$ **(1 mark)**

b. Sodium acetate is very soluble in water and will be a good electrolyte. The sodium acetate solution will have to be either Solution I, II, or IV. **(1 mark)**

c. Since sodium acetate forms a basic solution, chlorophenol red will show red in solution. The combination of red indicator colour and high electrical conductivity reduce the identification to one possibility. **(1 mark)**

d. The sodium acetate solution is Solution **IV**. **(1 mark)**

15. a. The pH of the 0.10 mol/L $HI_{(aq)}$ can be determined as follows:

$$\left[H_3O^+_{(aq)}\right] = \frac{\%\text{ reaction}}{100} \times [\text{acid}]$$
$$= \frac{100}{100} \times 0.10 \text{ mol/L}$$
$$= 0.10 \text{ mol/L}$$

$$\text{pH} = -\log(0.10)$$
$$= 1.00$$

The pH of the $HI_{(aq)}$ solution will be 1.00.

The pH of the 0.10 mol/L $CH_3COOH_{(aq)}$ can be determined as follows:

$$\left[H_3O^+_{(aq)}\right] = \frac{\%\text{ reaction}}{100} \times [\text{acid}]$$
$$= \frac{1.3}{100} \times 0.10 \text{ mol/L}$$
$$= 0.0013 \text{ mol/L}$$

$$\text{pH} = -\log(0.0013)$$
$$= 2.89$$

or

$$\left[H_3O^+_{(aq)}\right] = \sqrt{K_a\left[CH_3COOH_{(aq)}\right]}$$
$$\left[H_3O^+_{(aq)}\right] = \sqrt{1.8\times10^{-5} \text{ mol/L}(0.10 \text{ mol/L})}$$
$$= 1.3416\times10^{-3} \text{ mol/L}$$

$$\text{pH} = -\log\left(1.3416\times10^{-3}\right)$$
$$= 2.87$$

The pH of the $CH_3COOH_{(aq)}$ solution will be 2.89 (or 2.87). **(4 marks)**

(**Note:** The slight difference in pH values will not affect the answer in b.)

b.

Indicator	Solution A	Solution B
methyl orange	red	red
orange IV	red	yellow

(2 marks)

c. The red/red indicator colour combination supports a theoretical pH of 1. Solution A must be $HI_{(aq)}$.

The red/yellow indicator colour combination supports a theoretical pH of 2.89 (2.87). Solution B must be $CH_3COOH_{(aq)}$. **(2 marks)**

Part D: True or False

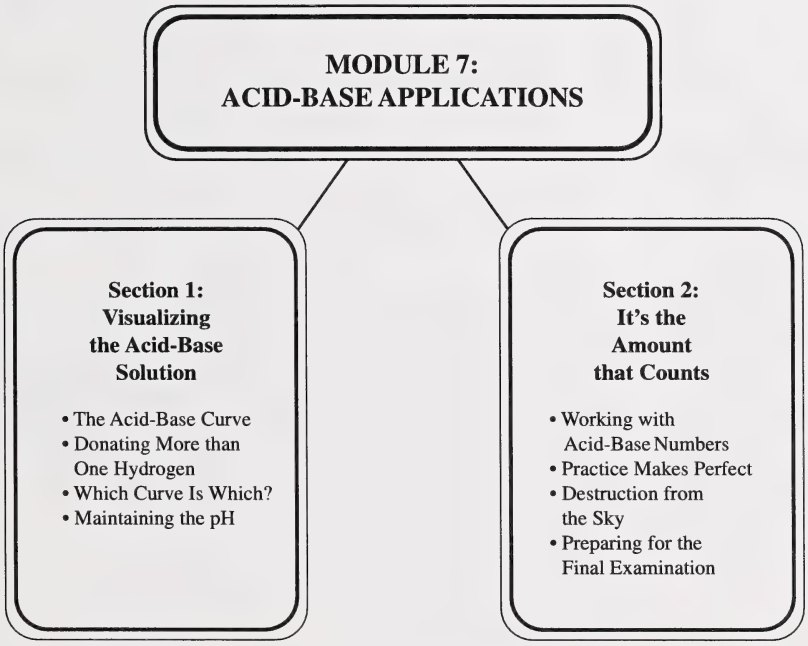
16. a. true c. true e. true g. true

b. false d. false f. true h. false **(4 marks)**

Module 7: Acid-Base Applications

Overview

In Module 6 the concepts of Arrhenius and Brønsted-Lowry acids and bases were introduced. In Module 7 these concepts are applied to investigate the pH curves of monoprotic and polyprotic substances, buffers, and the stoichiometric relationships in acid-base reactions. Several titration lab activities have been included to help develop these ideas. Acid deposition is also examined from an STS perspective.



Evaluation

The evaluation of this module will be based on two section assignments and one module assignment:

Section 1 Assignment	**30 marks**
Section 2 Assignment	**40 marks**
Final Module Assignment	**30 marks**
TOTAL	**100 marks**

Materials and Equipment

The following is a list of materials necessary for completing the investigations and activities in Module 7. Amounts stated represent requirements per student.

Section 1: Activity 1

Investigation 15.3: Demonstration of pH Curves

- 250 mL of 0.10 mol/L $HCl_{(aq)}$
- 60 mL of 0.10 mol/L $NaOH_{(aq)}$
- 60 mL of 0.10 mol/L $Na_2CO_{3(aq)}$
- pH 7 buffer solution
- bromothymol blue indicator
- methyl orange indicator
- distilled water
- pH meter
- 25 mL buret
- (2) 250 mL beakers or 250 mL Erlenmeyer flasks
- 100 mL graduated cylinder
- retort stand and clamp
- lab apron
- safety glasses

Section 1: Activity 3

Investigation 15.4: Buffers

- 3 g of $Na_2HPO_4 \bullet 7H_2O_{(s)}$
- 2 g of $NaH_2PO_4 \bullet H_2O_{(s)}$
- 10 mL of 0.10 mol/L $HCl_{(aq)}$
- 10 mL of 0.10 mol/L $NaOH_{(aq)}$
- water
- pH (pHydrion) paper or pH meter
- lab apron
- 2 eyedroppers
- laboratory scoop
- centigram balance or pan balance
- (3) 100 mL or 250 mL beakers
- 100 mL volumetric flask and stopper
- 100 mL graduated cylinder
- stirring rod or equivalent
- safety glasses

Section 1: Enrichment

Investigation: Concentration and pH Curve of a Weak Acid

- 25 mL household vinegar
- 40 mL of 0.10 mol/L $NaOH_{(aq)}$
- pH 7 buffer solution
- 25 mL buret and stand
- funnel
- 50 mL or 100 mL graduated cylinder
- 100 mL beaker or Erlenmeyer flask
- pH meter
- lab apron
- safety glasses

Section 2: Activity 2

Investigation 15.5: Ammonia Analysis

- 1.0 g of $Na_2CO_{3(aq)}$
- 100 mL of approximately 0.10 mol/L $HCl_{(aq)}$
- 5.0 mL of household ammonia
- wash bottle and distilled water
- methyl orange indicator
- methyl red indicator
- 100 mL volumetric flask and stopper
- 25 mL buret and stand
- funnel
- 10 mL pipet and bulb
- 100 mL beaker (or 250 mL Erlenmeyer flask)
- eyedropper
- laboratory scoop
- centigram or pan balance
- lab apron
- safety glasses

Section 2: Enrichment

Investigation: Pain-Relief Tablets

- two types of pain-relief tablets (each must contain acetylsalicylic acid)
- 100 mL of 0.10 mol/L $NaOH_{(aq)}$
- phenolphthalein indicator
- 150 mL or 250 mL beaker (or Erlenmeyer flask)
- 25 mL buret and stand
- funnel
- distilled water
- centigram or pan balance

Additional Resources

Brinkerhoff, R.F. 1992. *One Minute Readings: Issues in Science, Technology, and Society.* Don Mills, Ontario: Addison-Wesley Publishing Company, Inc.

Kimball, Doug, Eugene Kuzub, and Milan Sanader. 1993. *Chemistry Laboratory Manual.* Don Mills, Ontario: Addison-Wesley Publishing Company, Inc.

Rayner-Canham, G., P. Le Couteur, P. Fisher, and R. Raap. 1989. *Chemistry: A Second Course.* Don Mills, Ontario: Addison-Wesley Publishing Company, Inc.

Whitman, R.L., E.E. Zinck, and R.A. Nalepa. 1982. *Chemistry Today.* 2d ed. Scarborough, Ontario: Prentice-Hall Canada, Inc.

Wilbraham, Antony C., Dennis D. Staley, Candace J. Simpson, and Michael S. Matta. 1992. *Chemistry International System of Units (SI) Edition.* Don Mills, Ontario: Addison-Wesley Publishing Company, Inc.

Zumdahl, Steven S. 1989. *Chemistry.* 2d ed. Toronto, Ontario: D.C. Heath and Company.

Possible Media

Videos

Planet Under Pressure Series. (1991) (ACCESS Network)
Includes segment Acid Assault.

Acid Rain: A North American Challenge. (1991) (ACCESS Network)

Section 1: Visualizing the Acid-Base Solution

Key Concepts

In this section, the students will be asked to draw and interpret the pH curves for monoprotic and polyprotic substances. The concept of equivalence point will be introduced, as well as the selection of an appropriate indicator to detect the indicator endpoint. Later, the concept of buffers will be discussed.

Teaching Suggestions

- If pH meters are not available, you may want to obtain some qualitative data using pH (pHydrion) paper. Quantitative data may be obtained from the Appendix.
- It is important to make the distinction between equivalence point and indicator endpoint as illustrated in the module. *Nelson Chemistry* does not have the same definitions for these terms as the students will encounter on the diploma examination.

Section 1: Assignment Answer Key (30 marks)

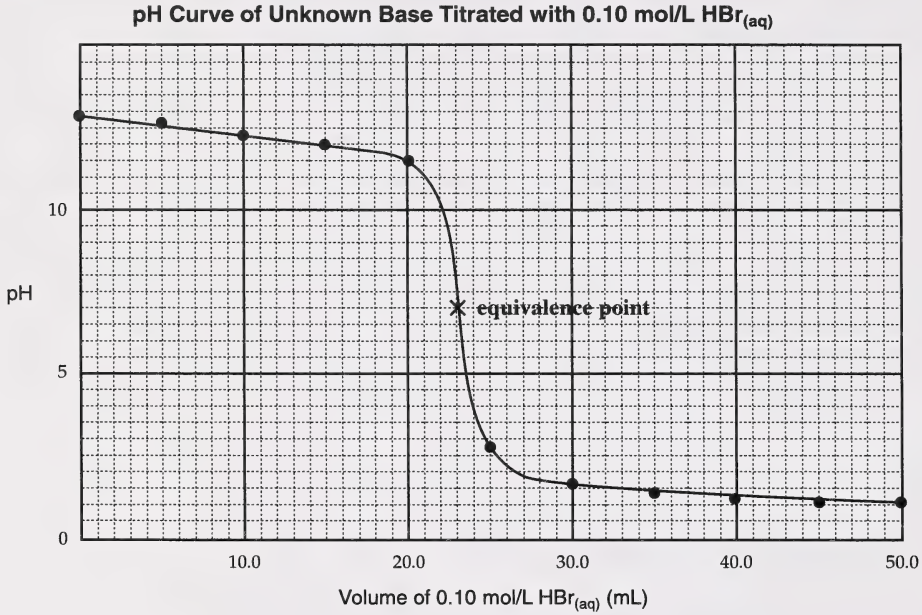
Part A: Multiple Choice

1. C 2. C 3. A 4. B 5. B **(5 marks)**

Part B: Written Response

6. An equivalence point is a point reached in a titration when chemically equivalent amounts of reactants are present. An indicator endpoint is the point reached in a titration when a properly chosen indicator changes colour. There can be more than one equivalence point in a titration, but only one indicator endpoint. **(2 marks)**

7. a.



(3 marks)

b. The reaction would be complete at the midpoint of the steep vertical section of the curve (at a pH of approximately 7). This point should be marked with an **x** on the graph in question 7.a. **(1 mark)**

c. Bromothymol blue, litmus, or phenol red could be used to determine when the reaction is complete. **(1 mark)**

d. The relatively horizontal section of the pH curve during the initial stages of the titration indicates that buffering is occurring. **(1 mark)**

e. The steep vertical section of the pH curve illustrates the rapid pH change as the equivalence point is approached and passed. Only a small volume of titrant added causes the large change in pH in this section of the curve. **(1 mark)**

f. The base must be strong because the reaction of a strong acid such as $HBr_{(aq)}$ and a strong monoprotic base would produce an equivalence point at a pH of 7. **(2 marks)**

8. **WEAK ACID-STRONG BASE VERSUS STRONG ACID-STRONG BASE**

Similarities	Differences
• Both pH curves have one steep vertical section. • Both pH curves start low in pH and end high in pH. • Both pH curves indicate a quantitative reaction.	• The midpoint region of a weak acid-strong base pH curve is higher in pH than the strong acid-strong base pH curve. • The buffer region on a weak acid-strong base pH curve is not as flat (horizontal) as a strong acid-strong base pH curve. • The weak acid-strong base pH curve generally starts higher and ends lower in pH than a strong acid-strong base pH curve. • The vertical section of the pH curve is shorter for a weak acid-strong base titration than a strong acid-strong base titration.

(4 marks)

9. a. The design may be as follows:

Small volumes of 0.10 mol/L $NaOH_{(aq)}$ are added continuously to a fixed and identical volume of each of the samples. After each addition, the pH of the mixture is recorded. The procedure is continued until the volume of titrant added is over double the initial volume of each sample. (**Note:** In this design the $HCl_{(aq)}$ supplied was not required.) **(3 marks)**

b. A pH curve would have to be drawn for each sample titrated. Because $HOOCCOOH_{(aq)}$ is a polyprotic acid, it will have two sharp changes in its pH curve. The pH curve for the $HI_{(aq)}$ solution will have only one sharp pH change and an equivalence point close to pH = 7. The titration of the $CH_3COOH_{(aq)}$ solution will show one sharp pH change as well, but its equivalence point will be greater than a pH of 7. **(3 marks)**

10. SA, A

$CH_3COOH_{(aq)}$, $CH_3COO^-{}_{(aq)}$, $K^+{}_{(aq)}$, $OH^-{}_{(aq)}$, $H_2O_{(l)}$

B, —, SB, B

$$CH_3COOH_{(aq)} + OH^-{}_{(aq)} \overset{>99\%}{\underset{\text{or favours products}}{\rightleftarrows}} CH_3COO^-{}_{(aq)} + H_2O_{(l)}$$ **(2 marks)**

11. SA, A, A

$H_3O^+{}_{(aq)}$, $I^-{}_{(aq)}$, $NH_4^+{}_{(aq)}$, $Cl^-{}_{(aq)}$, $NH_{3(aq)}$, $H_2O_{(l)}$

B, B, SB, B

$$H_3O^+{}_{(aq)} + NH_{3(aq)} \overset{>99\%}{\underset{\text{or favours products}}{\rightleftarrows}} NH_4^+{}_{(aq)} + H_2O_{(l)}$$ **(2 marks)**

Section 2: It's the Amount that Counts

Key Concepts

In the first activity the students will learn how to solve acid-base stoichiometry problems using nonionic or net ionic equations. In Activity 2, they will apply these skills to solve more sophisticated questions in Lab Exercises 15F and 15G. They will also perform a titration to analyse a household ammonia solution. Finally, in the last activity, students will examine the roles of science, technology, and society as they tackle the problem of acid deposition.

Teaching Suggestions

The analysis of the household ammonia solution will require several lab periods. To reduce the time required, you may want to develop the lab procedure as a class or prepare the primary standard solution for the class.

Section 2: Assignment Answer Key (40 marks)

Part A: Multiple Choice

1. D 2. C 3. B 4. A 5. C 6. D 7. A **(7 marks)**

Part B: Written Response

8. a. $Mg(OH)_{2(s)} + 2\,HCl_{(aq)} \overset{>99\%}{\rightleftarrows} MgCl_{2(aq)} + 2\,H_2O_{(l)}$ **(1 mark)**

b. $$m_{(Mg(OH)_2)} = \frac{0.250\ \cancel{mol\ HCl}}{\cancel{L}} \times 32.2\ m\cancel{L} \times \frac{1\ \cancel{mol\ Mg(OH)_2}}{2\ \cancel{mol\ HCl}} \times \frac{58.33\ g}{\cancel{mol\ Mg(OH)_2}}$$

$= 234.78$ mg

$= 0.235$ g The mass of $Mg(OH)_2$ is 0.235 g. **(4 marks)**

c. $$\%\ mass = \frac{0.23478\ g}{0.53\ g} \times 100\%$$

$= 44\%$ **(1 mark)**

d. The main error could be that only a single trial was performed. **(1 mark)**

9. $H_3X_{(aq)} + 3\,LiOH_{(aq)} \overset{>99\%}{\rightleftarrows} Li_3X_{(aq)} + 3\,H_2O_{(l)}$

$C = 0.0115$ mol/L $C = 0.100$ mol/L

$v = ?$ $v = 16.8$ mL

$$v_{(H_3X)} = \frac{0.100\ \cancel{mol\ LiOH}}{\cancel{L}} \times 16.8\ m\cancel{L} \times \frac{1\ \cancel{mol\ H_3X}}{3\ \cancel{mol\ LiOH}} \times \frac{1\ L}{0.0115\ \cancel{mol\ H_3X}}$$

$= 48.7$ mL

The volume of the acid sample is 48.7 mL. **(5 marks)**

10. $Sr(OH)_{2(aq)} + 2\,HNO_{3(aq)} \overset{>99\%}{\rightleftarrows} Sr(NO_3)_{2(aq)} + 2\,H_2O_{(l)}$

$v = 15.0$ mL $v = 8.4$ mL

$C = ?$ $C = 0.150$ mol/L

$$C_{(Sr(OH)_2)} = \frac{0.150\ \cancel{mol\ HNO_3}}{\cancel{L}} \times 8.4\ m\cancel{L} \times \frac{1\ \cancel{mol\ Sr(OH)_2}}{2\ \cancel{mol\ HNO_3}} \times \frac{1}{15.0\ m\cancel{L\ Sr(OH)_2}}$$

$= 0.0420$ mol/L

The concentration of $Sr(OH)_{2(aq)}$ is 0.0420 mol/L. **(6 marks)**

volume of acid $= 14.8\ mL - 6.4\ mL$

$= 8.4$ mL

11. a. **Step 1** The phenol red should be red in both of the basic solutions ($LiOH_{(aq)}$ and $Ba(OH)_{2(aq)}$). It should be yellow in both of the acidic solutions ($HI_{(aq)}$ and $H_2SO_{4(aq)}$).

Step 2 One of the acid samples will require about twice the amount of base as the other acid sample to reach its equivalence point.

Step 3 One of the base samples will require about twice the amount of acid as the other base sample to reach its equivalence point. **(3 marks)**

b. The acid and base samples were identified as described in Step 1 of answer a. The acid sample requiring twice the base volume is $H_2SO_{4(aq)}$ since $H_2SO_{4(aq)}$ is a polyprotic acid as compared to $HI_{(aq)}$ which is monoprotic. Since $Ba(OH)_{2(aq)}$ is a polyprotic base, it will require twice the volume of acid to neutralize it as compared to $LiOH_{(aq)}$. **(2 marks)**

12. a. A measured mass of each of the acid samples could be dissolved in distilled water and then titrated with 0.10 mol/L $KOH_{(aq)}$, using phenolphthalein as the indicator. **(2 marks)**

b. Since the molar mass of each acid is distinctly different for $C_7H_{15}COOH_{(s)}$ and $C_9H_{19}COOH_{(s)}$, the molar mass of the sample could be calculated from the data and compared to the theoretical values. **(2 marks)**

13. Suggestions for answers are given for both opinions.

Opinion A

Acid deposition is a definite threat to the environment. It has been estimated that 32 million metric tonnes of sulphur dioxide gas are released into the atmosphere each year in North America. The sulphur dioxide reacts with water in the atmosphere to produce sulphurous acid and sulphuric acid. These acids then return to Earth as acid deposition (acid rain, hail, snow, and fog).

There are many examples of the devastation this acid deposition causes. One case of scientific research into the effects of acid deposition on the environment is the case study of Lake 223 in Northern Canada. This seven-year study, where sulphuric acid was systematically added to a lake, saw almost all aquatic life disappear after the pH was lowered to and maintained at pH = 5.0.

Another case showing the effects of acid deposition is in Sudbury, Ontario (in the 1950s). The area around a smelter, which releases sulphur dioxide into the atmosphere, showed a dramatic decline in plant life and soil fertility.

The effects of acid deposition are three-fold:

- It leaches out nutrients from leaves and needles, causing a weakening of plantlife.
- It leaches out nutrients from the soil, starving the roots of plants.
- It releases aluminum ions from soil, preventing plants from absorbing nutrients. The released aluminum also seeps into rivers and lakes, killing the fish by causing suffocation.

The effects of acid deposition are well-documented and pose a serious threat to the environment. The causes of acid deposition must be shut off or reduced at the source – vehicles and power plants burning fossil fuels, and polluting metal smelters – before irreversible damage is done to the environment.

Opinion B

Acid deposition is not a proven threat to the environment. There is no disputing the fact that sulphur dioxide and nitrogen oxide emissions create acid deposition. What is in dispute, though, is the extent to which this acid deposition poses a proven threat to the environment. A 1988 U.S. federal task force studying the effects of acid deposition concluded that relatively few lakes have been damaged, and damage to human health, crops, and forests has yet to be proven. The task force also concluded that further harm is unlikely to occur over the next few decades.

There are several examples where the evidence of the effects of acid deposition has been disputed. For instance, evidence expressed by some scientists that links acid deposition in some regions to elevated tree mortality rates and decreased ring widths in trees, has been disputed by others, saying that the expressed effects could be due more to the decrease in mean annual temperatures in those regions. Damage originally blamed on acid deposition in areas such as the Black Forest in Germany has now been attributed to ground-level ozone. Some researchers actually found that plant seedlings deficient in nutrients benefited from a painting of acid deposition.

Advances in technology in recent years, such as the liming of lakes to neutralize the effects of acid deposition, and the introduction of scrubbers in smelter smokestacks have been very successful in reducing sulphur dioxide emissions. Scrubbers can reduce the acid deposition-causing gases by as much as 90%.

In conclusion, with the increased awareness of society as to the effects of acid deposition, and the advances of technology, acid deposition should be reduced to the point where the implied threat to the environment has been controlled. **(6 marks)**

Final Module Assignment Answer Key (30 marks)

Part A: Multiple Choice

1.	A	4.	B	7.	D
2.	D	5.	C	8.	D
3.	B	6.	C	9.	A **(9 marks)**

Part B: Numerical Response

10. | 1 | 4 | 3 | 2 | **(1 mark)**

11. | 2 | . | 5 | 0 | **(1 mark)**

Part C: Written Response

12. The following are five possible errors in the graph.

- Error 1

The initial pH of the KOH solution should be 13.3.

$$K_w = \left[H_3O^+_{(aq)}\right]\left[OH^-_{(aq)}\right]$$

$$\frac{1.00\times10^{-14}\ \text{mol}^2}{\text{L}^2} = \left[H_3O^+_{(aq)}\right]0.20\ \text{mol/L}$$

$$\left[H_3O^+_{(aq)}\right] = 5.0\times10^{-14}\ \text{mol/L}$$

$$\text{pH} = -\log\left[H_3O^+_{(aq)}\right]$$

$$\text{pH} = -\log\left(5.0\times10^{-14}\right)$$

$$\text{pH} = 13.3$$

- Error 2

  The equivalence point for the titration of a strong acid and a strong base should be 7. The equivalence point on this graph occurs at a pH of approximately 10.

- Error 3

  The volume of 0.10 mol/L HI required to neutralize 20.0 mL of 0.20 mol/L KOH should be 40.0 mL.

  $$HI_{(aq)} + KOH_{(aq)} \rightarrow KI_{(aq)} + H_2O_{(l)}$$

  $$V_{(HI)} = \frac{0.20\ \text{mol}}{1\ \text{L}} \times 0.0200\ \text{L} \times \frac{1\ \text{mol}}{1\ \text{mol}} \times \frac{1\ \text{L}}{0.10\ \text{mol}}$$
  $$= 40.0\ \text{mL}$$

- Error 4

  The title is incorrect. It should state Titration of Potassium Hydroxide with Hydroiodic Acid.

- Error 5

  The graph should drop down to a pH of about 2 and then gradually decrease towards a pH of about 1. **(4 marks)**

13. No. The $HBr_{(aq)}$ was not completely neutralized, as shown in the following calculation.

$$HBr_{(aq)} + NaOH_{(aq)} \overset{>99\%}{\rightleftarrows} H_2O_{(l)} + NaBr_{(aq)}$$

or

$$H_3O^+_{(aq)} + OH^-_{(aq)} \overset{>99\%}{\rightleftarrows} 2\,H_2O_{(l)}$$

$$3.75\ \text{mmol}\left\{\begin{matrix}25.0\ \text{mL} \\ 0.15\ \text{mol/L}\end{matrix}\right. \quad \left.\begin{matrix}15.0\ \text{mL} \\ 0.21\ \text{mol/L}\end{matrix}\right\} 3.15\ \text{mmol}$$

	$H_3O^+_{(aq)}$	$OH^-_{(aq)}$
initial moles (mmol)	3.75	3.15
reacted moles (mmol)	3.15	3.15
excess moles (mmol)	0.60	0.00

There were 0.60 mmol of $H_3O^+_{(aq)}$ $\left(HBr_{(aq)}\right)$ in excess, which leaves the solution acidic. **(3 marks)**

14. $CH_3COOH_{(aq)} + NaOH_{(aq)} \overset{>99\%}{\rightleftarrows} NaCH_3COO_{(aq)} + H_2O_{(l)}$

$v = 50.0$ mL $\quad v = 26.8$ mL

$C = ?$ $\quad C = 0.175$ mol/L

$$C_{(CH_3COOH)} = \frac{0.175\ \cancel{\text{mol NaOH}}}{\cancel{\text{L}}} \times 26.8\ \cancel{\text{mL}} \times \frac{1\ \text{mol}\ \cancel{CH_3COOH}}{1\ \cancel{\text{mol NaOH}}} \times \frac{1}{50.0\ \cancel{\text{mL}}\ \cancel{CH_3COOH}}$$

$$= 0.0938\ \text{mol/L}$$

The concentration of the acetic acid in the vinegar is 0.0938 mol/L. **(3 marks)**

15. If an acid is added to the system, then $HPO_4^{2-}{}_{(aq)}$ will react with it to maintain a near constant pH.

$$HPO_4^{2-}{}_{(aq)} + H_3O^+{}_{(aq)} \overset{>99\%}{\rightleftarrows} H_2PO_4^-{}_{(aq)} + H_2O_{(l)}$$

If a base is added to the system, then $H_2PO_4^-{}_{(aq)}$ will react with it to maintain a near constant pH.

$$H_2PO_4^-{}_{(aq)} + OH^-{}_{(aq)} \overset{>99\%}{\rightleftarrows} HPO_4^{2-}{}_{(aq)} + H_2O_{(l)}$$ **(3 marks)**

16. Acid deposition is any type of acid precipitation – rain, fog, snow, or hail. Acid deposition forms when sulphur dioxide or nitrogen oxides are released into the atmosphere and react with water and oxygen to form sulphuric acid or nitric acid.

Examples

$SO_{2(g)} + H_2O_{(l)} \rightleftarrows H_2SO_{3(aq)}$

$SO_{3(g)} + H_2O_{(l)} \rightleftarrows H_2SO_{4(aq)}$

$NO_{2(g)} + H_2O_{(l)} \rightleftarrows HNO_{3(aq)}$

These acids leach nutrients from leaves, leach minerals from the soil, and drastically reduce the ability of aquatic animals to reproduce. **(4 marks)**

17. The student should hand in a completed Science Skills Spreadsheet (self-assessment and teacher-assessment values should be done for Modules 1-6). Written responses will vary. Does the students' assessment match the data shown by the spreadsheet? Has the student improved in science skills or in the assessment of his or her skills? **(2 marks)**

Final Test

Note:

- Scientific calculators are recommended when writing this test. A chemistry data booklet is included with this test.
- The data booklet included with this test does not include an acid-base indicator colour plate nor a colour plate of common aqueous ions. If you require these pages, you must obtain a Chemistry Data Booklet from Alberta Education – Student Evaluation Branch.

Included here is the answer key to the final test and the student's copy of the final test which is designed for photocopying and possible faxing.

Note:

The answer key and student's copy of this final test should be kept secure by the teacher. Students should not have access to this test until it is assigned in a supervised situation. The answers should be stored securely and retained by the teacher at all times.

CHEMISTRY 30 FINAL TEST ANSWER KEY

PART A – MULTIPLE CHOICE (44 marks)

1 C	9 A	17 A	25 A	33 B	41 A
2 A	10 B	18 A	26 B	34 B	42 B
3 B	11 A	19 B	27 C	35 D	43 B
4 D	12 D	20 D	28 B	36 C	44 C
5 A	13 B	21 D	29 A	37 B	
6 D	14 C	22 C	30 A	38 D	
7 B	15 A	23 B	31 C	39 D	
8 A	16 C	24 C	32 B	40 B	

PART B – NUMERICAL RESPONSE (12 marks)

1	2	3	4	5	6
48.3	1.25	3412	7531	5314	1467

7	8	9	10	11	12
21.6	0.36	3241	4231	2.71	5531

PART C – WRITTEN RESPONSE (24 marks)

1. a. $C_4H_{10(g)} + \frac{13}{2} O_{2(g)} \rightarrow 4\ CO_{2(g)} + 5\ H_2O_{(g)}$

$(-126.5) \quad (0) \quad 4(-393.5) \quad 5(-241.8)$

$$\Delta H = \left[4\text{ mol}(-393.5\text{ kJ/mol}) + 5\text{ mol}(-241.8\text{ kJ/mol})\right] - \left[1\text{ mol}(-126.5\text{ kJ/mol}) + \tfrac{13}{2}\text{ mol}(0\text{ kJ/mol})\right]\text{ kJ}$$
$$= -2656.5\text{ kJ}$$

$$H_{com} = \frac{-2656.5\text{ kJ}}{1\ \cancel{\text{mol } C_4H_{10}}} \times \frac{1\ \cancel{\text{mol } C_4H_{10}}}{58.14\text{ g}}$$
$$= -45.69\text{ kJ/g}$$

The heat of combustion of butane is -45.69 kJ/g. **(4 marks)**

b. I would recommend propane for the winter camping trip because

- It has a slightly higher energy yield per unit mass.
- It would cause less problems in weather below –10°C. Butane will not vaporize below –10°C and will not flow from the tank because the vapour pressure is lower than atmospheric pressure. **(2 marks)**

(communication: 2 marks)

2. **Acid Rain**

Acid rain will increase the rate of corrosion of iron because the combination of $H^+_{(aq)}$ ions (from the acid rain) and $O_{2(g)}$ is a stronger oxidizing agent than $H_2O_{(l)}$ with $O_{2(g)}$ (the more common atmospheric oxidizing agent). The $H^+_{(aq)}/O_{2(g)}$ oxidizing agent will create a stronger reaction with iron and cause faster corrosion.

Salt

Dissolved salts will increase the rate of corrosion of iron. The salt will increase the concentration of electrolyte which allows a better flow of charge. If electrons and charge can move more quickly, corrosion will occur faster.

Cathodic Protection

Cathodic protection will slow the rate of corrosion. If a metal that is a stronger reducing agent than iron is attached directly to the iron, the iron will act as a cathode and will not be oxidized.

Example

Attach a piece of zinc to a piece of iron and place in a $NaCl_{(aq)}$ solution.

		OA		SOA	
$Zn_{(s)}$,	$Fe_{(s)}$,	$Na^+_{(aq)}$,	$Cl^-_{(aq)}$,	$H_2O_{(l)}$,	$O_{2(g)}$
SRA	**RA**		**RA**	**RA**	

The zinc is the anode; the $Fe_{(s)}$ becomes the cathode, around which the hydrogen in the $H_2O_{(l)}$ is reduced. **(6 marks)**

(communication: 2 marks)

3. a. $HCN_{(aq)} \rightleftarrows H^+_{(aq)} + CN^-_{(aq)}$

or

$HCN_{(aq)} + H_2O_{(l)} \underset{\text{favours reactants}}{\rightleftarrows} H_3O^+_{(aq)} + CN^-_{(aq)}$ **(1 mark)**

b. $$K_a(HCN) = \frac{\left[H_3O^+_{(aq)}\right]\left[CN^-_{(aq)}\right]}{\left[HCN_{(aq)}\right]}$$

$$6.2\times10^{-10}\ \text{mol/L} = \frac{(x)(x)}{(0.150\ \text{mol/L})}$$

$$9.3\times10^{-11}\ (\text{mol/L})^2 = x^2$$

$$x = 9.644\times10^{-6}\ \text{mol/L}$$

$$\left[H_3O^+_{(aq)}\right] = 9.6\times10^{-6}\ \text{mol/L}$$

$$pH = -\log\left(9.644\times10^{-6}\right)$$

$$= 5.02$$

The pH of the $HCN_{(aq)}$ is 5.02. **(2 marks)**

c. If $Ni(NO_3)_{2(aq)}$ was added to the $HCN_{(aq)}$ equilibrium, the $Ni^{2+}_{(aq)}$ ions would react with the $CN^-_{(aq)}$ ions and create a precipitate. This removes $CN^-_{(aq)}$ ions from the solution, causing the $HCN_{(aq)}$ equilibrium to shift to the right. This would increase the $\left[H_3O^+_{(aq)}\right]$ and therefore decrease the pH. **(2 marks)**

d. If a person was given a substance that would precipitate the $CN^-_{(aq)}$ ions out of solution, such as $Ni(NO_3)_{2(aq)}$, this would reduce the poisonous effects of $CN^-_{(aq)}$ on the body. The substance would have to be non-poisonous itself. **(1 mark)**

(communication: 2 marks)

CHEMISTRY 30

FINAL TEST

GENERAL INSTRUCTIONS

YOU HAVE **THREE** HOURS TO COMPLETE THIS TEST. Work through the entire test answering the questions you are sure you know. You will then be able to concentrate on the questions of which you are not quite sure.

TOTAL MARKS: 80

PART A: Multiple Choice 44 marks

PART B: Numerical Response 12 marks

PART C: Written Response 24 marks

Note: Scientific calculators are recommended when writing this test.

A chemistry data booklet is included with this test.

CHEMISTRY 30 FINAL TEST ANSWER SHEET

PART A – MULTIPLE CHOICE

1 Ⓐ Ⓑ Ⓒ Ⓓ	9 Ⓐ Ⓑ Ⓒ Ⓓ	17 Ⓐ Ⓑ Ⓒ Ⓓ	25 Ⓐ Ⓑ Ⓒ Ⓓ	33 Ⓐ Ⓑ Ⓒ Ⓓ	41 Ⓐ Ⓑ Ⓒ Ⓓ
2 Ⓐ Ⓑ Ⓒ Ⓓ	10 Ⓐ Ⓑ Ⓒ Ⓓ	18 Ⓐ Ⓑ Ⓒ Ⓓ	26 Ⓐ Ⓑ Ⓒ Ⓓ	34 Ⓐ Ⓑ Ⓒ Ⓓ	42 Ⓐ Ⓑ Ⓒ Ⓓ
3 Ⓐ Ⓑ Ⓒ Ⓓ	11 Ⓐ Ⓑ Ⓒ Ⓓ	19 Ⓐ Ⓑ Ⓒ Ⓓ	27 Ⓐ Ⓑ Ⓒ Ⓓ	35 Ⓐ Ⓑ Ⓒ Ⓓ	43 Ⓐ Ⓑ Ⓒ Ⓓ
4 Ⓐ Ⓑ Ⓒ Ⓓ	12 Ⓐ Ⓑ Ⓒ Ⓓ	20 Ⓐ Ⓑ Ⓒ Ⓓ	28 Ⓐ Ⓑ Ⓒ Ⓓ	36 Ⓐ Ⓑ Ⓒ Ⓓ	44 Ⓐ Ⓑ Ⓒ Ⓓ
5 Ⓐ Ⓑ Ⓒ Ⓓ	13 Ⓐ Ⓑ Ⓒ Ⓓ	21 Ⓐ Ⓑ Ⓒ Ⓓ	29 Ⓐ Ⓑ Ⓒ Ⓓ	37 Ⓐ Ⓑ Ⓒ Ⓓ	
6 Ⓐ Ⓑ Ⓒ Ⓓ	14 Ⓐ Ⓑ Ⓒ Ⓓ	22 Ⓐ Ⓑ Ⓒ Ⓓ	30 Ⓐ Ⓑ Ⓒ Ⓓ	38 Ⓐ Ⓑ Ⓒ Ⓓ	
7 Ⓐ Ⓑ Ⓒ Ⓓ	15 Ⓐ Ⓑ Ⓒ Ⓓ	23 Ⓐ Ⓑ Ⓒ Ⓓ	31 Ⓐ Ⓑ Ⓒ Ⓓ	39 Ⓐ Ⓑ Ⓒ Ⓓ	
8 Ⓐ Ⓑ Ⓒ Ⓓ	16 Ⓐ Ⓑ Ⓒ Ⓓ	24 Ⓐ Ⓑ Ⓒ Ⓓ	32 Ⓐ Ⓑ Ⓒ Ⓓ	40 Ⓐ Ⓑ Ⓒ Ⓓ	

PART B – NUMERICAL RESPONSE

1	2	3	4	5	6
7	8	9	10	11	12

Name of Student _____ Student I.D. # _____

Name of School _____ Date _____

Value

PART A: MULTIPLE CHOICE

44

Instructions

- Consider all numbers used in the questions to be the result of a measurement.
- Read each question carefully and decide which of the choices **best** completes the statement or answers the question.
- Locate that question number on the separate answer sheet provided and fill in the circle that corresponds to your choice.

Example

This diploma examination is for the subject of

A. biology
B. physics
C. chemistry
D. mathematics

Answer Sheet

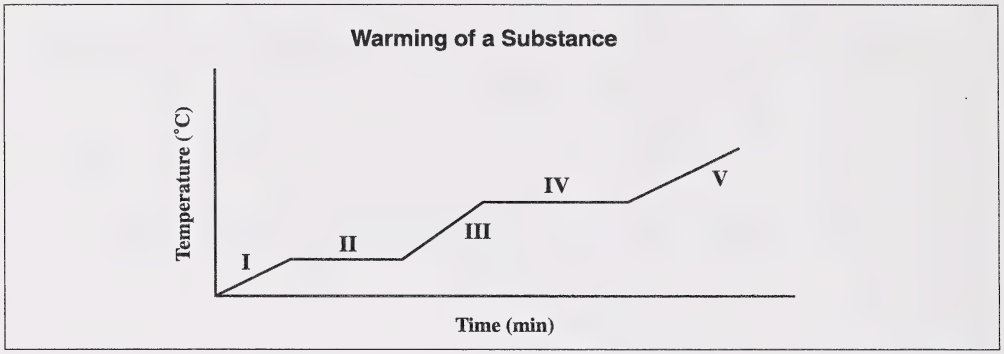
Ⓐ Ⓑ ● Ⓓ

- **Use an HB pencil only.**
- If you wish to change an answer, erase **all** traces of your first answer.
- Each question is worth one mark.
- **Do not turn the page to start the examination until told to do so by the presiding examiner.**

1. A phase change of a substance results in a change primarily in the substance's

   A. mass
   B. potential energy
   C. kinetic energy
   D. type of chemical bonding

Use the following diagram to answer question 2.



2. The sections of the diagram where the substance exists in two phases are

   A. I and III
   B. II and IV
   C. III and IV
   D. I and V

3. Which equation represents an endothermic chemical change?

   A. $H_2O_{(l)} \rightarrow H_2O_{(s)}$
   B. $C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)} + 393.5\ kJ$
   C. $CH_{4(g)} + 74.8\ kJ \rightarrow C_{(s)} + 2\ H_{2(g)}$
   D. $SiH_{4(g)} + 2\ O_{2(g)} \rightarrow SiO_{2(g)} + 2\ H_2O_{(l)} \quad \Delta H = -1516\ kJ$

4. The combustion of a 5.00 g sample of cellulose in a bomb calorimeter causes 2.35 kg of water to increase in temperature from 20.4°C to 24.5°C. What is the heat produced by this reaction?

   A. 85.9 J
   B. 8.07 kJ
   C. 19.4 kJ
   D. 40.4 kJ

Use the following information to answer question 5.

A commercial cold-pack consists of an outer pouch containing $NH_4NO_{3(s)}$ and an inner pouch containing water. When the contents of the pouches are mixed, a cooling effect is observed.

$$\Delta H^\circ_f \text{ for } NH_4NO_{3(s)} = -365.6 \text{ kJ/mol}$$
$$\Delta H^\circ_f \text{ for } NH_4NO_{3(aq)} = -339.4 \text{ kJ/mol}$$

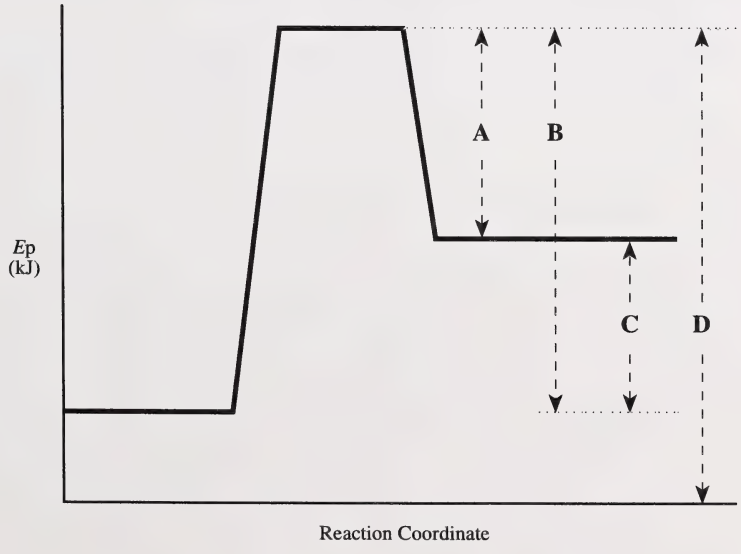
5. When the cold-pack is activated, the observed cooling effect suggests that the energy of the pack

   A. increases and the energy of the surroundings decreases
   B. decreases and the energy of the surroundings increases
   C. increases and the energy of the surroundings increases
   D. decreases and the energy of the surroundings decreases

6. A major industrial problem is the corrosion of metals into their oxides. Which metallic oxide requires the greatest amount of energy, per mole, to be refined back into the pure metal?

   A. $CuO_{(s)}$
   B. $PbO_{2(s)}$
   C. $Fe_2O_{3(s)}$
   D. $Al_2O_{3(s)}$

7. On the following diagram, which letter represents the heat of reaction?



Use the following information to answer question 8.

$$CH_3COCH_{3(l)} + 4\ O_{2(g)} \rightarrow 3\ CO_{2(g)} + 3\ H_2O_{(l)} \quad \Delta H = -1791.0\ kJ$$

8. The energy change when 1.00 g of $CH_3COCH_{3(l)}$ reacts is

   A. 30.8 kJ which is released to the surroundings
   B. 30.8 kJ which is absorbed by the reaction
   C. 1791.0 kJ which is released to the surroundings
   D. 1791.0 kJ which is absorbed by the reaction

9. The metal that requires the most energy to increase the temperature of 1.00 g of it 1.00°C is

   A. aluminum
   B. copper
   C. nickel
   D. lead

Use the following information to answer question 10.

When glucose is metabolized in the body, the reaction it undergoes is represented by the following overall chemical equation:

$$C_6H_{12}O_{6(s)} + 6\ O_{2(g)} \rightarrow 6\ CO_{2(g)} + 6\ H_2O_{(l)}$$

10. According to the given equation what mass of glucose would release 194 kJ of energy when metabolized in the body?

    A. 6.53 g
    B. 6.87 g
    C. 12.5 g
    D. 13.8 g

11. Which reaction involves the greatest energy change?

    A. $^1_1H + {}^3_1H \rightarrow {}^4_2He$
    B. $C_{12}H_{22}O_{11(s)} + 12\ O_{2(g)} \rightarrow 12\ CO_{2(g)} + 11\ H_2O_{(g)}$
    C. $H_{2(g)} + O_{2(g)} \rightarrow H_2O_{2(l)}$
    D. $H_2O_{(s)} \rightarrow H_2O_{(g)}$

Use the following information to answer question 12.

$$O_{2(g)} \rightarrow 2\,O_{(g)} \qquad \Delta H = +498 \text{ kJ}$$
$$3\,O_{2(g)} \rightarrow 2\,O_{3(g)} \qquad \Delta H = +284 \text{ kJ}$$

12. The heat of reaction for $O_{3(g)} \rightarrow 3\,O_{(g)}$ is

A. +214 kJ
B. +356 kJ
C. +463 kJ
D. +605 kJ

Use the following data to answer question 13.

Compound	Molar Heat of Formation (kJ/mol)	pH of 0.10 mol/L Solution	K_a
$HF_{(g)}$	−271.1	2.11	6.6×10^{-4}
$HCl_{(g)}$	−92.3	1.00	1.3×10^{6}
$HBr_{(g)}$	−36.4	1.00	1.0×10^{9}
$HI_{(g)}$	+26.5	1.00	3.2×10^{9}

13. A generalization about these compounds that can be made from the data is that

A. strong acids have strong intramolecular bonds
B. compounds with strong intramolecular bonds have a low pH
C. the most stable compound has the highest pH
D. the weaker the intramolecular bond, the higher the pH

14. If a neutral atom becomes positively charged, then it has

A. been reduced
B. been oxidized
C. lost a proton
D. gained a neutron

15. Chlorine gas has an irritating odour and can cause lung damage. To prevent chlorine from escaping into the air, it can be bubbled through $Na_2S_2O_{3(aq)}$. The reaction that occurs is

$$4\ Cl_{2(g)} + S_2O_3^{2-}{}_{(aq)} + 5\ H_2O_{(l)} \rightarrow 2\ SO_4^{2-}{}_{(aq)} + 10\ H^+{}_{(aq)} + 8\ Cl^-{}_{(aq)}.$$

The oxidizing agent in this reaction is

A. $Cl_{2(g)}$
B. $S_2O_3^{2-}{}_{(aq)}$
C. $H_2O_{(l)}$
D. $Cl^-{}_{(aq)}$

16. Which of the following industrial processes could not be classified as an oxidation-reduction reaction?

A. combustion of methane
B. electrolysis of salt
C. sulphur dioxide reacts with water to form sulphurous acid
D. discharge of a lead storage battery

17. Which of the following is a biochemical oxidation-reduction reaction?

A. $Zn_{(s)} + Cu(NO_3)_{2(aq)} \rightarrow Cu_{(s)} + Zn(NO_3)_{2(aq)}$
B. $NaOH_{(aq)} + HCl_{(aq)} \rightarrow NaCl_{(aq)} + HOH_{(l)}$
C. $C_6H_{12}O_{6(s)} + 6\ O_{2(g)} \rightarrow 6\ HOH_{(l)} + 6\ CO_{2(g)}$
D. $CH_3COOH_{(aq)} + NH_{3(aq)} \rightarrow NH_4CH_3COO_{(aq)}$

18. Given the hypothetical reactions

$$2\ X^-{}_{(aq)} + Y_{2(s)} \rightarrow \text{reacts spontaneously}$$
$$2\ Z^-{}_{(aq)} + Y_{2(s)} \rightarrow \text{no reaction}$$
$$2\ Z^-{}_{(aq)} + W_{2(s)} \rightarrow \text{reacts spontaneously,}$$

another spontaneous reaction would be

A. $Z_{2(s)} + 2\ X^-{}_{(aq)} \rightarrow X_{2(s)} + 2\ Z^-{}_{(aq)}$
B. $X_{2(s)} + 2\ Y^-{}_{(aq)} \rightarrow 2\ X^-{}_{(aq)} + Y_{2(s)}$
C. $X_{2(s)} + 2\ W^-{}_{(aq)} \rightarrow 2\ X^-{}_{(aq)} + W_{2(s)}$
D. $Y_{2(s)} + 2\ W^-{}_{(aq)} \rightarrow 2\ Y^-{}_{(aq)} + W_{2(s)}$

19. Fiona prepared a standard acidified solution of $Fe^{2+}_{(aq)}$ and then titrated a $KMnO_{4(aq)}$ solution of unknown concentration. Why did Fiona acidify the $Fe^{2+}_{(aq)}$ standard solution?

A. $Fe^{2+}_{(aq)}$ cannot act as a reducing agent without acid.
B. The acid changes $Fe^{2+}_{(aq)}$ to $Fe_{(s)}$ to form the standard solution.
C. $MnO_4^-{}_{(aq)}$ will not act as an oxidizing agent without the acid.
D. Acid is required to dilute the $Fe^{2+}_{(aq)}$ to a lower concentration.

20. A piece of magnesium metal reacts when it is placed into nitric acid. The balanced redox reaction is

A. $Mg_{(s)} + 2\ NO_3^-{}_{(aq)} \rightarrow Mg(NO_3)_{2(aq)} + NO_{2(g)}$
B. $Mg_{(s)} + H^+_{(aq)} + NO_3^-{}_{(aq)} \rightarrow Mg^{2+}_{(aq)} + NO_{2(g)} + OH^-_{(aq)}$
C. $Mg_{(s)} + 3\ H^+_{(aq)} + \frac{3}{2}\ NO_3^-{}_{(aq)} \rightarrow Mg^{2+}_{(aq)} + \frac{3}{2}\ NO_{2(g)} + H_2O_{(l)}$
D. $Mg_{(s)} + 4\ H^+_{(aq)} + 2\ NO_3^-{}_{(aq)} \rightarrow Mg^{2+}_{(aq)} + 2\ NO_{2(g)} + 2\ H_2O_{(l)}$

21. A researcher wants to test aluminum, zinc, chromium, and copper individually for their suitability as a dental filling. Keeping in mind many foods are acidic, which metal would be most suitable to investigate as a filling?

A. aluminum
B. zinc
C. chromium
D. copper

Use the following information to answer question 22.

$$2\ X_{(s)} + 3\ Y^{2+}_{(aq)} \rightarrow 2\ X^{3+}_{(aq)} + 3\ Y_{(s)} \qquad \Delta E^\circ = +0.90\ V$$

$$Z^{2+}_{(aq)} + Y_{(s)} \rightarrow Z_{(s)} + Y^{2+}_{(aq)} \qquad \Delta E^\circ = +0.50\ V$$

22. If metal $X_{(s)}$ is aluminum, then metal $Z_{(s)}$ is

A. $Zn_{(s)}$
B. $Ni_{(s)}$
C. $Cr_{(s)}$
D. $Fe_{(s)}$

23. Which of the following would be a spontaneous redox reaction?

A. $Pb_{(s)} + Zn^{2+}_{(aq)} \rightarrow Zn_{(s)} + Pb^{2+}_{(aq)}$

B. $Sn^{4+}_{(aq)} + 2\ Fe^{2+}_{(aq)} \rightarrow Sn^{2+}_{(aq)} + 2\ Fe^{3+}_{(aq)}$

C. $Co_{(s)} + Cu^{2+}_{(aq)} \rightarrow Cu_{(s)} + Co^{2+}_{(aq)}$

D. $O_{2(g)} + 2\ HOH_{(l)} + 4\ Br^{-}_{(aq)} \rightarrow 2\ Br_{2(l)} + 4\ OH^{-}_{(aq)}$

24. In an analysis to determine the concentration of $Sn^{2+}_{(aq)}$ ions in a tin ore solution, a 25.0 mL sample of the solution is acidified and titrated to a pink endpoint with 40.0 mL of 0.200 mol/L $KMnO_{4(aq)}$. The concentration of $Sn^{2+}_{(aq)}$ ions in the sample is

A. 1.25 mol/L
B. 0.800 mol/L
C. 0.128 mol/L
D. 0.100 mol/L

Use the following information to answer question 25.

Following is a list of statements concerning electrochemical and electrolytic cells:

I. An external power source is required.
II. The reaction is spontaneous.
III. The net potential difference is negative.
IV. The cations migrate to the cathode.

25. The TRUE statements that apply only to electrolytic cells are

A. I, II, and III
B. I, II, and IV
C. I, III, and IV
D. II, III, and IV

26. A student constructed an electrochemical cell using an electrode of aluminum in aqueous aluminum chloride solution and an electrode of nickel in aqueous nickel(II) chloride solution. Assuming standard conditions, the net potential of this cell should be

A. −1.92 V
B. −1.40 V
C. +1.40 V
D. +1.92 V

27. What mass of aluminum is deposited during the electrolysis of molten aluminum bromide if 30.0 A flow through the cell for 4.85 h?

A. 146 g
B. 48.8 g
C. 1.46 g
D. 0.0351 g

28. Which of the following is at equilibrium?

A. Bunsen burner flame with constant height and colour
B. water level is constant behind a dam
C. an unopened bottle of pop at room temperature
D. glowing coals in a fireplace

Use the following information to answer question 29.

The Haber process is an industrial method of producing ammonia for use in fertilizers and other products. It is represented by the following equation:

$$N_{2(g)} + 3\,H_{2(g)} \rightleftarrows NH_{3(g)} + 92.2\ kJ$$

29. Which of the following changes in the equilibrium conditions should favour an increased yield in ammonia?

A. decrease the temperature and increase the pressure
B. decrease the temperature and decrease the pressure
C. increase the temperature and decrease the pressure
D. increase the temperature and increase the pressure

Use the following information to answer question 30.

In the hypothetical reaction,

$$2\,A_{(g)} + B_{(g)} \rightleftarrows C_{(g)} + 2\,D_{(g)},$$

6.0 mol of $A_{(g)}$ and 2.0 mol of $B_{(g)}$ were introduced into a 2.0 L flask and allowed to react at a constant temperature. When equilibrium in the system was reached, 1.0 mol of $B_{(g)}$ remained.

30. The equilibrium constant, *K*, for the given reaction is

A. 0.25
B. 0.44
C. 1.0
D. 8.0

31. If the pH of a solution changes from 2.5 to 4.5, the $\left[H_3O^+_{(aq)}\right]$ has

A. increased by a factor of 10^2
B. decreased by a factor of 10^2
C. increased by a factor of 2
D. decreased by a factor of 2

32. The pH of a 4.0×10^{-2} mol/L monoprotic acid solution was measured and found to be 2.10. For this acid, the percent ionization with water is

A. 0.79%
B. 4.0%
C. 20%
D. 80%

Use the following information to answer question 33.

An industrial chemist did an analysis of four substances used in various processes at the company for which she worked. The following data reflect her analysis:

Substance	Concentration (mol/L)	pH
W	10.0	14.0
X	0.10	1.0
Y	10.0	4.0
Z	1.0	0.0

33. The concentrated, weak acid in the substances tested is

A. W
B. X
C. Y
D. Z

Use the following information to answer question 34.

$$HSO_3^-{}_{(aq)} + CN^-{}_{(aq)} \rightleftarrows HCN_{(aq)} + SO_3^{2-}{}_{(aq)}$$

34. Which sequence will correctly identify, respectively, the Brønsted-Lowry acids and bases in the given equation?

A. base acid base acid
B. base base acid acid
C. acid base acid base
D. base acid acid base

35. Which of the following does not represent a conjugate acid-base pair?

A. $H_3O^+_{(aq)} - H_2O_{(l)}$

B. $HCN_{(aq)} - CN^-_{(aq)}$

C. $HCl_{(aq)} - Cl^-_{(aq)}$

D. $CH_3COOH_{(aq)} - OH^-_{(aq)}$

Use the following information to answer question 36.

The addition of various indicators to separate samples of an aqueous solution produces the following results:

Test Tube	Indicator Added	Colour of Solution
1	orange IV	yellow
2	bromocresol green	blue
3	phenol red	red
4	thymolphthalein	blue
5	indigo carmine	blue

36. The most probable $\left[H_3O^+_{(aq)}\right]$ for the aqueous solution is

A. 2.0×10^{-12} mol/L

B. 1.0×10^{-11} mol/L

C. 2.5×10^{-10} mol/L

D. 3.2×10^{-9} mol/L

37. Each of the following substances is amphiprotic except

A. $HS^-_{(aq)}$

B. $HCO_3^-{}_{(aq)}$

C. $NH_4^+{}_{(aq)}$

D. $H_2PO_4^-{}_{(aq)}$

38. When an aqueous solution of baking soda, $NaHCO_{3(aq)}$, is used to clean up the deposits around the battery posts in a car battery, a vigorous reaction results and a gas is given off. The "lime water" test identifies the gas as carbon dioxide. A correct explanation of this reaction is that the

A. baking soda reacted with the lead post and produced hydrogen and carbon dioxide
B. aqueous solution of baking soda contained a large amount of dissolved carbon dioxide that was driven off by the heat generated in the reaction
C. corrosion contained some hydrocarbon materials that were burned by the reaction, thus producing carbon dioxide
D. carbonic acid produced when the hydrogen carbonate ion reacted with sulphuric acid immediately broke down into water and carbon dioxide

39. Which one of the following species would be considered polyprotic?

A. $HS^-_{(aq)}$
B. $HCN_{(aq)}$
C. $NH_4{}^+_{(aq)}$
D. $HBO_3{}^{2-}_{(aq)}$

40. The endpoint of a titration occurs when

A. the pH curve levels off
B. the pH of the solution is zero
C. the indicator changes colour
D. a stoichiometric amount of acid and base have been mixed

Use the following information to answer question 41.

A chemist performed a titration experiment and found that the volume of acid used from the burette was lower than the calculated theoretical volume needed to neutralize the base. Some of the suggested experimental errors were:

I. Too much base was pipetted into the flask.
II. The endpoint was passed.
III. The wrong indicators were chosen.
IV. There was water in the burette when the acid was added.
V. There was water in the flask when the base was pipetted into it.

41. Which of the suggested experimental errors would account for the low volume of acid used?

A. III only
B. II and III
C. I, III, and IV
D. I, II, III, IV, and V

42. The mass of barium hydroxide required to completely neutralize 125.5 mL of 1.50 mol/L hydrochloric acid would be

A. 7.20 g
B. 16.1 g
C. 29.1 g
D. 32.2 g

43. The pH at the equivalence point of an acid-base titration is 3.8. This result would be consistent with the titration of a

A. strong acid with a strong base
B. weak acid with a strong base
C. strong acid with a weak base
D. weak acid with a weak base

44. Which of the following is a buffer system?

A. $HCl_{(aq)} + NaOH_{(aq)}$
B. $CH_3COOH_{(aq)} + NaCH_3COO_{(aq)}$
C. $HCl_{(aq)} + H_2SO_{4(aq)}$
D. $CH_3COOH_{(aq)} + HCl_{(aq)}$

Value

PART B: NUMERICAL RESPONSE

12

Instructions

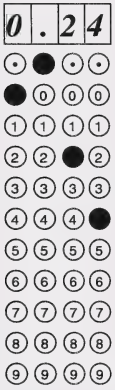
- Consider all numbers used in the questions to be the result of a measurement.
- Read each question carefully.
- Record your answer on the answer sheet provided by writing it in the boxes and then filling in the corresponding circles.
- **Enter the first digit of your answer in the left-hand box and leave any unused boxes blank.**
- Use an HB pencil only.
- If you wish to change an answer, erase **all** traces of your first answer.
- Each question is worth one mark.

Sample Calculation Question and Solution

The mass in kilograms of silver produced when 2.20 mol of silver nitrate reacts with excess copper is _____ kg.
(Record your answer to three digits.)

$$\text{mass}_{Ag} = 0.220 \text{ mol} \times 107.87 \text{ g/mol}$$
$$= 23.7314 \text{ g}$$
$$= 0.24 \text{ kg (recorded to three digits)}$$

Record 0.24 on the answer sheet →



Sample Correct-order Question and Solution

When the following subjects are arranged in alphabetical order, the order is _____.
(Record all four digits.)

1. mathematics
2. chemistry
3. biology
4. physics

Answer 3, 2, 1, 4

Record 3214 on the answer sheet →

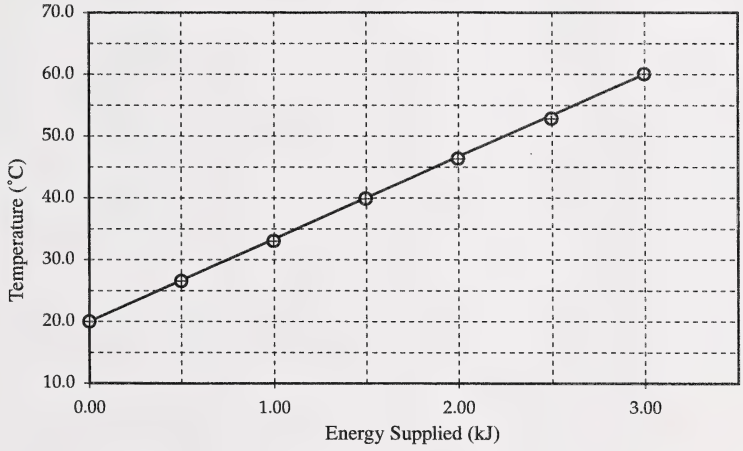
Start Part B immediately.

1. In a recycling plant, the amount of heat needed to raise the temperature of 84.6 kg of aluminum from room temperature (25.0°C) to its melting point is _____ MJ.
(Record your answer to three digits.)

RECORD YOUR ANSWER ON THE ANSWER SHEET.

Use the following information to answer question 2.

A 60.0 g sample of an unidentified substance was heated and the following data was collected.



2. The specific heat capacity of the unidentified sample is _____ J/g°C.
(Record your answer to three digits.)

RECORD YOUR ANSWER ON THE ANSWER SHEET.

Use the following information to answer question 3.

A sample of crude oil is heated and introduced into the bottom of a fractional distillation tower at an oil refinery. The following four substances are separated and collected as they ascend the tower:

Substance	Boiling Point (°C)
1. gasoline, $C_8H_{18(l)}$	110
2. natural gas, $CH_{4(g)}$	–164
3. paraffin wax, $C_{25}H_{52(s)}$	402
4. furnace oil, $C_{15}H_{32(l)}$	271

3. The order in which the four substances are collected (starting at the bottom of the tower), by their numbers, is _____. (Record all four digits.)

RECORD YOUR ANSWER ON THE ANSWER SHEET.

4. The oxidation number of chlorine in each of the ions ClO_4^-, ClO_3^-, ClO_2^-, ClO^-, is respectively ____, ____, ____, ____.

RECORD YOUR ANSWER ON THE ANSWER SHEET.

Use the following information to answer question 5.

1. $Cu^{2+}_{(aq)}$
2. $NO_3^-{}_{(aq)}$
3. $Sn^{2+}_{(aq)}$
4. $Cu_{(s)}$
5. $Sn_{(s)}$
6. $H_2O_{(l)}$

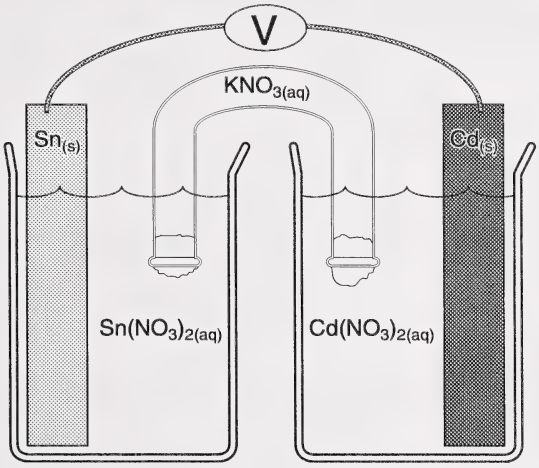
5. A standard voltaic (electrochemical) cell is constructed with 1.0 mol/L $Cu(NO_3)_{2(aq)}$, $Cu_{(s)}$, 1.0 mol/L $Sn(NO_3)_{2(aq)}$, and $Sn_{(s)}$. The cell notation for this standard cell is outlined below. The substances included in the cell notation in the order shown, as selected from the given numbered species, would be

$$\underset{\text{anode}}{\_\_\_\_} \,|\, \underset{\text{electrolyte}}{\_\_\_\_} \,\|\, \underset{\text{electrolyte}}{\_\_\_\_} \,|\, \underset{\text{cathode}}{\_\_\_\_}$$

RECORD YOUR ANSWER ON THE ANSWER SHEET.

Use the following information to answer question 6.

The nine given statements concern the following electrochemical cell:



1. $Sn_{(s)}$ is the cathode.
2. ΔE° is less than zero.
3. $Sn_{(s)}$ is the strongest oxidizing agent.
4. $Cd^{2+}_{(aq)}$ will flow through the salt bridge.
5. Electrons will move towards $Cd_{(s)}$.
6. $Cd_{(s)}$ is the strongest reducing agent.
7. The mass of $Sn_{(s)}$ will increase.
8. $Cd^{2+}_{(aq)}$ will decrease in oxidation number.
9. $Sn^{2+}_{(aq)}$ will flow through the salt bridge.

6. From the information given, the true statements, in numerical order, are ___, ___, ___, ___.

RECORD YOUR ANSWER ON THE ANSWER SHEET.

7. An electrochemical cell, $Zn_{(s)} \mid Zn^{2+}{}_{(aq)} \parallel Ag^{+}{}_{(aq)} \mid Ag_{(s)}$, is constructed using zinc and silver electrodes. If the anode mass changes by 6.54 g, then the predicted mass change for the cathode is _____ g.
(Record your answer to three digits.)

RECORD YOUR ANSWER ON THE ANSWER SHEET.

Use the following information to answer question 8.

The following hypothetical reaction has reached equilibrium at SATP:

$$A_{(g)} + 2\,B_{(g)} \rightleftarrows 2\,C_{(g)}$$

The equilibrium constant (K) is 4.0 for this reaction. At equilibrium, the $[A] = 0.20$ mol/L and the $[B] = 0.40$ mol/L.

8. The equilibrium concentration of $C_{(g)}$ is _____ mol/L.
(Record your answer to three digits.)

RECORD YOUR ANSWER ON THE ANSWER SHEET.

Use the following information to answer question 9.

Four unknown monoprotic acids were analysed and found to have the following equilibrium constants:

Acid	K_a (at SATP)
1	4.3×10^{-11}
2	1.6×10^{-5}
3	2.9×10^{-2}
4	8.2×10^{-8}

9. The order of the acids from strongest to weakest is ___, ___, ___, ___.

RECORD YOUR ANSWER ON THE ANSWER SHEET.

Use the following information to answer question 10.

1. $NH_4^+{}_{(aq)} + CO_3^{2-}{}_{(aq)} \rightleftarrows HCO_3^-{}_{(aq)} + NH_{3(aq)}$
2. $HNO_{2(aq)} + CO_3^{2-}{}_{(aq)} \rightleftarrows HCO_3^-{}_{(aq)} + NO_2^-{}_{(aq)}$
3. $HCN_{(aq)} + CO_3^{2-}{}_{(aq)} \rightleftarrows HCO_3^-{}_{(aq)} + CN^-{}_{(aq)}$
4. $HSO_4^-{}_{(aq)} + CO_3^{2-}{}_{(aq)} \rightleftarrows HCO_3^-{}_{(aq)} + SO_4^{2-}{}_{(aq)}$

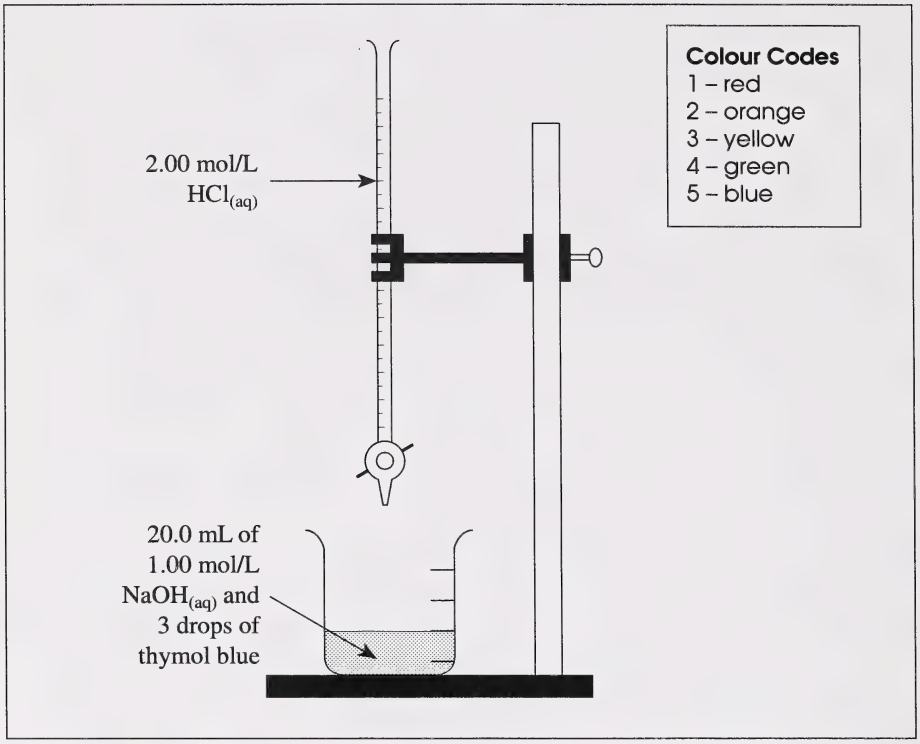
10. The order of the given reactions, by their numbers, from most to least complete at equilibrium is ——, ——, ——, ——.

RECORD YOUR ANSWER ON THE ANSWER SHEET.

11. When 25 mL of 0.10 mol/L $NaOH_{(aq)}$ is mixed with 26 mL of 0.10 mol/L $HBr_{(aq)}$, the pH of the resulting solution is _____.
(Record your answer to three digits.)

RECORD YOUR ANSWER ON THE ANSWER SHEET.

Use the following diagram and colour-code chart to answer question 12.



12. The code for the colour of the solution in the beaker when

- no $HCl_{(aq)}$ is added is _____ (Record in first column)
- 5.0 mL of $HCl_{(aq)}$ are added is _____ (Record in second column)
- 10.0 mL of $HCl_{(aq)}$ are added is _____ (Record in third column)
- 15.0 mL of $HCl_{(aq)}$ are added is _____ (Record in fourth column)

RECORD YOUR ANSWER ON THE ANSWER SHEET.

Value

PART C: WRITTEN RESPONSE

24

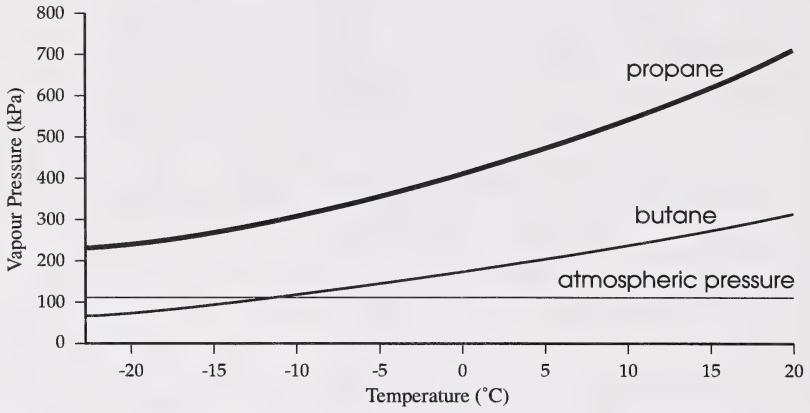
Instructions

- Consider all numbers used in the questions to be the result of a measurement.
- Read each question carefully.
- Write your answers in the space provided as neatly as possible.
- For full marks, your answers **must show all** pertinent explanations, calculations, and formulas.
- Your answers **should be** presented in a well-organized manner using complete sentences for a written response, and correct units and significant digits for a numerical response.

Start Part C immediately.

Use the following information to answer question 1.

Most camping stoves contain fuel in a tank, and the designer of the stove must find a way to move the fuel, a little at a time, to the burner. For propane and butane stoves, this is easy because the fuel is stored under pressure greater than atmospheric pressure and it comes out on its own as soon as the valve is opened. (Heat of combustion of propane $= -46.3$ kJ/g)



(8 marks)

1. a. Camp stoves often use compressed butane gas as a fuel. Determine the heat of combustion of butane in **kJ/g**. ($H_2O_{(g)}$ is one of the products.)

Name of Student _____ Student I.D. # _____

Name of School _____ Date _____

b. Which of the two fuels – propane or butane – would you recommend for a **winter** camping trip? Give two valid reasons to justify your answer. (Consider energy yield and operation in cold weather in your explanation.)

Name of Student _____ Student I.D. # _____

Name of School _____ Date _____

(8 marks) 2. Discuss, using chemical principles and equations where applicable, the effect of acid rain, salt, and cathodic protection on the rate of corrosion of iron.

Name of Student _____ Student I.D. # _____

Name of School _____ Date _____

(8 marks) 3. Hydrogen cyanide gas is very poisonous. It dissolves well in water to create $HCN_{(aq)}$.

a. Write the equilibrium equation for $HCN_{(aq)}$ ionizing in water.

b. Calculate the pH of a 0.150 mol/L solution of $HCN_{(aq)}$. (You can use the K_a approximation.)

c. If cyanide ions $\left(CN^{-}{}_{(aq)}\right)$ have very low solubility with nickel(II) ions $\left(Ni^{2+}{}_{(aq)}\right)$, predict how the pH of a 0.150 mol/L $HCN_{(aq)}$ solution would be affected by the addition of $Ni(NO_3)_{2(aq)}$. Explain your prediction.

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d. The $CN^-_{(aq)}$ is the actual poisonous part of $HCN_{(aq)}$.

Note: The following question is only theoretical.

If $CN^-_{(aq)}$ was somehow injested into the stomach, based on the information in this question, describe a possible (theoretical) antidote to cyanide $\left(CN^-_{(aq)}\right)$ poisoning.

_____

_____

_____

_____

_____

Name of Student _____ Student I.D. # _____

Name of School _____ Date _____

Chemistry
Data Booklet

Note:

- This booklet provides most of the data needed for your work in this course.
- This data booklet is similar to the booklet used when writing the Chemistry 30 diploma examination.
- Familiarize yourself with the layout and the contents of this data booklet so that you will feel comfortable using it.

Distance Learning

Alberta
EDUCATION

1	2	3	4	5	6	7	8	9
IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB	

1 H 2.1 1+,1– 1.01 hydrogen								
3 Li 1.0 1+ 6.94 lithium	4 Be 1.5 2+ 9.01 beryllium							
11 Na 0.9 1+ 22.99 sodium	12 Mg 1.2 2+ 24.31 magnesium							
19 K 0.8 1+ 39.10 potassium	20 Ca 1.0 2+ 40.08 calcium	21 Sc 1.3 3+ 44.96 scandium	22 Ti 1.5 4+, 3+ 47.90 titanium	23 V 1.6 5+, 4+ 50.94 vanadium	24 Cr 1.6 3+, 2+ 52.00 chromium	25 Mn 1.5 2+, 4+ 54.94 manganese	26 Fe 1.8 3+, 2+ 55.85 iron	27 Co 1.8 2+, 3+ 58.93 cobalt
37 Rb 0.8 1+ 85.47 rubidium	38 Sr 1.0 2+ 87.62 strontium	39 Y 1.3 3+ 88.91 yttrium	40 Zr 1.4 4+ 91.22 zirconium	41 Nb 1.6 5+, 3+ 92.91 niobium	42 Mo 1.8 6+ 95.94 molybdenum	*43 Tc* 1.9 7+ (98.91) technetium	44 Ru 2.2 3+, 4+ 101.07 ruthenium	45 Rh 2.2 3+ 102.91 rhodium
55 Cs 0.7 1+ 132.91 cesium	56 Ba 0.9 2+ 137.33 barium	57-71	72 Hf 1.3 4+ 178.49 hafnium	73 Ta 1.5 5+ 180.95 tantalum	74 W 1.7 6+ 183.85 tungsten	75 Re 1.9 7+ 186.21 rhenium	76 Os 2.2 4+ 190.20 osmium	77 Ir 2.2 4+ 192.22 iridium
87 Fr 0.7 1+ (223.02) francium	88 Ra 0.9 2+ (226.03) radium	89-*103*	*104 Unq* — (266.11) unnilquadium	*105 Unp* — (262.11) unnilpentium	*106 Unh* — (263.12) unnilhexium	*107 Uns* — (262.12) unnilseptium	*108 Uno* — (265) unniloctium	*109 Une* — (266) unnilennium

57 La 1.1 3+ 138.91 lanthanum	58 Ce 1.1 3+ 140.12 cerium	59 Pr 1.1 3+ 140.91 praseodymium	60 Nd 1.2 3+ 144.24 neodymium	*61 Pm* — 3+ (144.91) promethium	62 Sm 1.2 3+,2+ 150.35 samarium
89 Ac 1.1 3+ (227.03) actinium	90 Th 1.3 4+ (232.04) thorium	91 Pa 1.5 5+, 4+ (231.04) protactinium	92 U 1.7 6+,4+ 238.03 uranium	*93 Np* 1.3 5+ (237.05) neptunium	*94 Pu* 1.3 4+, 6+ (244.06) plutonium

Table of Polyatomic Ions

acetate	CH_3COO^-	cyanide	CN^-	silicate	SiO_3^{2-}
ammonium	NH_4^+	hydroxide	OH^-	sulphate	SO_4^{2-}
benzoate	$C_6H_5COO^-$	iodate	IO_3^-	sulphite	SO_3^{2-}
borate	BO_3^{3-}	nitrate	NO_3^-	hydrogen sulphide	HS^-
carbonate	CO_3^{2-}	nitrite	NO_2^-	hydrogen sulphate	HSO_4^-
hydrogen carbonate	HCO_3^-	oxalate	$OOCCOO^{2-}$	hydrogen sulphite	HSO_3^-
chlorate	ClO_3^-	permanganate	MnO_4^-	thiocyanate	SCN^-
hypochlorite	ClO^-	phosphate	PO_4^{3-}	thiosulphate	$S_2O_3^{2-}$
chromate	CrO_4^{2-}	hydrogen phosphate	HPO_4^{2-}		
dichromate	$Cr_2O_7^{2-}$	dihydrogen phosphate	$H_2PO_4^-$		

10	11	12	13	14	15	16	17	18
VIIIB	IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA or O

Note:
The legend at the right denotes the physical state of the elements at 101 kPa and 298.15 K (25°C).

Legend for the elements

Solid	Liquid	Gas
Natural	*Synthetic*	

Key

Atomic number → 1 H ← Symbol
Electronegativity → 2.1 1+, 1– ← Common Ion charge (first charge is most common)
Atomic molar mass → 1.01
Name → hydrogen

Based on $^{12}_{6}C$
( ) Indicates mass of the most stable isotope

								2 He — 4.00 helium
			5 B 2.0 10.81 boron	6 C 2.5 12.01 carbon	7 N 3.0 3– 14.01 nitrogen	8 O 3.5 2– 16.00 oxygen	9 F 4.0 1– 19.00 fluorine	10 Ne — 20.17 neon
			13 Al 1.5 3+ 26.98 aluminum	14 Si 1.8 28.09 silicon	15 P 2.1 3– 30.97 phosphorus	16 S 2.5 2– 32.06 sulphur	17 Cl 3.0 1– 35.45 chlorine	18 Ar — 39.95 argon
28 Ni 1.8 2+, 3+ 58.71 nickel	29 Cu 1.9 2+, 1+ 63.55 copper	30 Zn 1.6 2+ 65.38 zinc	31 Ga 1.6 3+ 69.72 gallium	32 Ge 1.8 4+ 72.59 germanium	33 As 2.0 3– 74.92 arsenic	34 Se 2.4 2– 78.96 selenium	35 Br 2.8 1– 79.90 bromine	36 Kr — 83.80 krypton
46 Pd 2.2 2+, 4+ 106.40 palladium	47 Ag 1.9 1+ 107.87 silver	48 Cd 1.7 2+ 112.41 cadmium	49 In 1.7 3+ 114.82 indium	50 Sn 1.8 4+, 2+ 118.69 tin	51 Sb 1.9 3+, 5+ 121.75 antimony	52 Te 2.1 2– 127.60 tellurium	53 I 2.5 1– 126.90 iodine	54 Xe — 131.30 xenon
78 Pt 2.2 4+, 2+ 195.09 platinum	79 Au 2.4 3+, 1+ 196.97 gold	80 Hg 1.9 2+, 1+ 200.59 mercury	81 Tl 1.8 1+, 3+ 204.37 thallium	82 Pb 1.8 2+, 4+ 207.19 lead	83 Bi 1.9 3+, 5+ 208.98 bismuth	84 Po 2.0 2+, 4+ (208.98) polonium	85 At 2.2 1– (209.98) astatine	86 Rn — (222.02) radon

63 Eu — 3+, 2+ 151.96 europium	64 Gd 1.1 3+ 157.25 gadolinium	65 Tb 1.2 3+ 158.93 terbium	66 Dy — 3+ 162.50 dysprosium	67 Ho 1.2 3+ 164.93 holmium	68 Er 1.2 3+ 167.26 erbium	69 Tm 1.2 3+ 168.93 thulium	70 Yb 1.1 3+, 2+ 173.04 ytterbium	71 Lu 1.2 3+ 174.97 lutetium
95 Am 1.3 3+, 4+ (243.06) americium	*96 Cm* — 3+ (247.07) curium	*97 Bk* — 3+, 4+ (247.07) berkelium	*98 Cf* — 3+ (242.06) californium	*99 Es* — 3+ (252.08) einsteinium	*100 Fm* — 3+ (257.10) fermium	*101 Md* — 2+, 3+ (258.10) mendelevium	*102 No* — 2+, 3+ (259.10) nobelium	*103 Lr* — 3+ (260.11) lawrencium

CHEMISTRY NOTATION

SYMBOL	TERM	UNITS
C	concentration	mol/L
c	specific heat capacity	J/(g•°C) or J/(g•K)
c	speed of light	m/s
E	energy	J
H	molar enthalpy (heat)	J/mol
I	current	A or C/s
K	equilibrium constant	varies
M	molar mass	g/mol
m	mass	g
n	moles	mol
p	pressure	kPa
Q	charge	C
R	gas constant	L•kPa/(K•mol)
T	temperature (absolute)	K
t	temperature (common)	°C
t	time	s
V	electrical potential	V or J/C
V	volume	L
Δ	delta (change in)	—
°	standard	—
a	acid	—
b	base	—
w	water	—
k	kinetic	—
p	potential	—
f	formation	—
com	combustion	—

CHEMISTRY

Miscellaneous

$H_2O_{(s)} \rightarrow H_2O_{(l)}$ $\Delta H = +6.03$ kJ

$H_2O_{(l)} \rightarrow H_2O_{(g)}$ $\Delta H = +40.8$ kJ

Room temperature = 298.15 K (25°C)

Standard pressure = 101.325 kPa

The Avogadro's number = 6.02×10^{23}

Ion product for water = 1.00×10^{-14} mol^2/L^2

Specific heat capacities:

$H_2O_{(s)}$ = 2.01 J/(g•°C)
$H_2O_{(l)}$ = 4.19 J/(g•°C)
$H_2O_{(g)}$ = 2.01 J/(g•°C)
$air_{(g)}$ = 1.02 J/(g•°C)

Speed of light = 3.00×10^8 m/s

Charge of 1.00 mol of electrons = 9.65×10^4 C

Mass of 1.00 mol of air = 29.18 g

Gas constant = 8.314 L•kPa/(K•mol)

Ideal Gas Law: $pV = nRT$

Quadratic equation: $x = \dfrac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

MELTING AND BOILING POINTS, AND SPECIFIC HEAT CAPACITY OF MOST ELEMENTS

NAME	SYMBOL	#	MELTING POINT (°C)	BOILING POINT (°C)	SPECIFIC HEAT* CAPACITY (J/g•°C)
aluminum	Al	13	660	2467	0.900
antimony	Sb	51	631	1750	0.205
argon	Ar	18	–189	–186	0.519
barium	Ba	56	725	1640	0.192
beryllium	Be	4	1278	2970	1.824
bismuth	Bi	83	271	1560	0.124
boron	B	5	2079	2550	1.025
bromine	Br	35	–7	59	0.473
cadmium	Cd	48	321	765	0.232
calcium	Ca	20	839	1484	0.653
cerium	Ce	58	798	3443	0.205
cesium	Cs	55	28	669	0.238
chlorine	Cl	17	–101	–35	0.477
chromium	Cr	24	1857	2672	0.448
cobalt	Co	27	1495	2870	0.456
copper	Cu	29	1083	2567	0.385
dysprosium	Dy	66	1412	2567	0.173
erbium	Er	68	1529	2868	0.168
europium	Eu	63	822	1527	0.176
fluorine	F	9	–220	–188	0.824
gadolinium	Gd	64	1313	3273	0.230
gallium	Ga	31	30	2403	0.372
germanium	Ge	32	937	2830	0.322
gold	Au	79	1064	2808	0.129
helium	He	2	–272	–269	5.188
holmium	Ho	67	1474	2700	0.164
hydrogen	H	1	–259	–253	14.267
indium	In	49	157	2080	0.234
iodine	I	53	114	184	0.427
iridium	Ir	77	2410	4130	0.133
iron	Fe	26	1535	2750	0.444
krypton	Kr	36	–157	–152	0.247
lanthanum	La	57	918	3464	0.197
lead	Pb	82	328	1740	0.159
lithium	Li	3	181	1342	3.556
lutetium	Lu	71	1663	3402	0.155
magnesium	Mg	12	649	1090	1.017
manganese	Mn	25	1244	1962	0.477
mercury	Hg	80	–39	357	0.138
molybdenum	Mo	42	2617	4612	0.251

* for room temperature state

MELTING AND BOILING POINTS, AND SPECIFIC HEAT CAPACITY OF MOST ELEMENTS (continued)

NAME	SYMBOL	#	MELTING POINT (°C)	BOILING POINT (°C)	SPECIFIC HEAT* CAPACITY (J/g•°C)
neodymium	Nd	60	1021	3074	0.205
neon	Ne	10	–249	–246	1.029
nickel	Ni	28	1453	2732	0.444
niobium	Nb	41	2468	4742	0.268
nitrogen	N	7	–210	–196	1.042
osmium	Os	76	3045	5027	0.131
oxygen	O	8	–218	–183	0.916
palladium	Pd	46	1554	3140	0.244
phosphorus	P	15	44	280	0.757
platinum	Pt	78	1772	3827	0.133
polonium	Po	84	254	962	0.126
potassium	K	19	63	760	0.753
praseodymium	Pr	59	931	3520	0.192
radium	Ra	88	700	1140	0.120
radon	Rn	86	–71	–62	0.094
rhenium	Re	75	3180	5627	0.138
rhodium	Rh	45	1965	3727	0.244
rubidium	Rb	37	39	686	0.360
ruthenium	Ru	44	2310	3900	0.238
samarium	Sm	62	1074	1794	0.180
scandium	Sc	21	1541	2836	0.556
selenium	Se	34	217	685	0.321
silicon	Si	14	1410	2355	0.703
silver	Ag	47	962	2212	0.237
sodium	Na	11	98	883	1.226
strontium	Sr	38	769	1384	0.301
sulphur	S	16	113	445	0.732
technetium	Tc	43	2172	4877	0.243
tellurium	Te	52	450	990	0.201
terbium	Tb	65	1356	3230	0.183
thallium	Tl	81	303	1457	0.128
thulium	Tm	69	1545	1950	0.160
tin	Sn	50	232	2270	0.213
titanium	Ti	22	1660	3287	0.523
tungsten	W	74	3410	5660	0.133
uranium	U	92	1132	3818	0.115
vanadium	V	23	1890	3380	0.485
xenon	Xe	54	–112	–107	0.158
ytterbium	Yb	70	819	1196	0.145
yttrium	Y	39	1522	3338	0.285
zinc	Zn	30	420	907	0.388
zirconium	Zr	40	1852	4377	0.281

* for room temperature state

STANDARD HEATS OF FORMATION AT 298.15 K (25°C)

NAME	FORMULA	ΔH°_f (kJ/mol)
aluminum oxide	$Al_2O_{3(s)}$	–1675.7
ammonia	$NH_{3(g)}$	– 46.1
ammonium chloride	$NH_4Cl_{(s)}$	–314.4
ammonium nitrate	$NH_4NO_{3(s)}$	–365.6
barium carbonate	$BaCO_{3(s)}$	–1216.3
barium chloride	$BaCl_{2(s)}$	–858.6
barium hydroxide	$Ba(OH)_{2(s)}$	–944.7
barium oxide	$BaO_{(s)}$	–553.5
barium sulphate	$BaSO_{4(s)}$	–1473.2
benzene	$C_6H_{6(l)}$	+49.0
butane	$C_4H_{10(g)}$	–126.5
calcium carbonate	$CaCO_{3(s)}$	–1206.9
calcium chloride	$CaCl_{2(s)}$	–795.8
calcium hydroxide	$Ca(OH)_{2(s)}$	–986.1
calcium oxide	$CaO_{(s)}$	– 635.1
calcium sulphate	$CaSO_{4(s)}$	–1434.1
carbon dioxide	$CO_{2(g)}$	–393.5
carbon monoxide	$CO_{(g)}$	–110.5
chromium(III) oxide	$Cr_2O_{3(s)}$	–1139.7
copper(I) oxide	$Cu_2O_{(s)}$	–168.6
copper(II) oxide	$CuO_{(s)}$	–157.3
copper(II) sulphate	$CuSO_{4(s)}$	–771.4
copper(I) sulphide	$Cu_2S_{(s)}$	–79.5
copper(II) sulphide	$CuS_{(s)}$	–53.1
ethane	$C_2H_{6(g)}$	–84.7
ethanoic acid (acetic acid)	$CH_3COOH_{(l)}$	– 484.5
ethanol	$C_2H_5OH_{(l)}$	–277.1
ethene (ethylene)	$C_2H_{4(g)}$	+52.3
ethyne (acetylene)	$C_2H_{2(g)}$	+226.7
glucose	$C_6H_{12}O_{6(s)}$	–1273.1
hydrogen bromide	$HBr_{(g)}$	–36.4
hydrogen chloride	$HCl_{(g)}$	–92.3
hydrogen fluoride	$HF_{(g)}$	–271.1
hydrogen iodide	$HI_{(g)}$	+26.5
hydrogen perchlorate	$HClO_{4(l)}$	– 40.6
hydrogen peroxide	$H_2O_{2(l)}$	–187.8
hydrogen sulphide	$H_2S_{(g)}$	–20.6
iron(III) oxide	$Fe_2O_{3(s)}$	–824.2
iron(II, III) oxide (magnetite)	$Fe_3O_{4(s)}$	–1118.4
lead(II) bromide	$PbBr_{2(s)}$	–278.7
lead(II) chloride	$PbCl_{2(s)}$	–359.4
lead(II) oxide (red)	$PbO_{(s)}$	–219.0
lead(IV) oxide	$PbO_{2(s)}$	–277.4
magnesium carbonate	$MgCO_{3(s)}$	–1095.8
magnesium chloride	$MgCl_{2(s)}$	– 641.3
magnesium hydroxide	$Mg(OH)_{2(s)}$	–924.5
magnesium oxide	$MgO_{(s)}$	– 601.7

STANDARD HEATS OF FORMATION AT 298.15 K (25°C) (continued)

NAME	FORMULA	ΔH°_f (kJ/mol)
magnesium sulphate	$MgSO_{4(s)}$	–1284.9
manganese(II) oxide	$MnO_{(s)}$	–385.2
manganese(IV) oxide	$MnO_{2(s)}$	–520.0
mercury(II) oxide (red)	$HgO_{(s)}$	–90.8
mercury(II) sulphide (red)	$HgS_{(s)}$	–58.2
methanal (formaldehyde)	$CH_2O_{(g)}$	–115.9
methane	$CH_{4(g)}$	–74.8
methanoic acid (formic acid)	$HCOOH_{(l)}$	– 424.7
methanol	$CH_3OH_{(l)}$	–239.0
nickel(II) oxide	$NiO_{(s)}$	–239.7
nitric acid	$HNO_{3(l)}$	–174.1
nitrogen dioxide	$NO_{2(g)}$	+33.2
nitrogen monoxide	$NO_{(g)}$	+90.2
octane	$C_8H_{18(l)}$	–250.0
pentane	$C_5H_{12(l)}$	–146.4
phosphorus pentachloride	$PCl_{5(s)}$	– 443.5
phosphorus trichloride (liquid)	$PCl_{3(l)}$	–319.7
phosphorus trichloride (vapour)	$PCl_{3(g)}$	–287.0
potassium bromide	$KBr_{(s)}$	–393.8
potassium chlorate	$KClO_{3(s)}$	–397.7
potassium chloride	$KCl_{(s)}$	– 436.7
potassium hydroxide	$KOH_{(s)}$	– 424.8
propane	$C_3H_{8(g)}$	–103.8
silicon dioxide	$SiO_{2(s)}$	–910.9
silver bromide	$AgBr_{(s)}$	–100.4
silver chloride	$AgCl_{(s)}$	–127.1
silver iodide	$AgI_{(s)}$	– 61.8
sodium bromide	$NaBr_{(s)}$	–361.1
sodium chloride	$NaCl_{(s)}$	– 411.2
sodium hydroxide	$NaOH_{(s)}$	– 425.6
sodium iodide	$NaI_{(s)}$	–287.8
sucrose	$C_{12}H_{22}O_{11(s)}$	–2225.5
sulphur dioxide	$SO_{2(g)}$	–296.8
sulphuric acid	$H_2SO_{4(l)}$	–814.0
sulphur trioxide (liquid)	$SO_{3(l)}$	– 441.0
sulphur trioxide (vapour)	$SO_{3(g)}$	–395.7
tin(II) chloride	$SnCl_{2(s)}$	–325.1
tin(IV) chloride	$SnCl_{4(l)}$	–511.3
tin(II) oxide	$SnO_{(s)}$	–285.8
tin(IV) oxide	$SnO_{2(s)}$	–580.7
water (liquid)	$H_2O_{(l)}$	–285.8
water (vapour)	$H_2O_{(g)}$	–241.8
zinc oxide	$ZnO_{(s)}$	–348.3
zinc sulphide	$ZnS_{(s)}$	–206.0

SOLUBILITY OF SOME COMMON IONIC COMPOUNDS IN WATER AT 298.15 K (25°C)

ION	GROUP IA NH_4^+ H^+ (H_3O^+)	ClO_3^- NO_3^- ClO_4^-	CH_3COO^-	Cl^- Br^- I^-	SO_4^{2-}	S^{2-}	OH^-	PO_4^{3-} SO_3^{2-} CO_3^{2-}
Solubility greater than or equal to 0.1 mol/L (very soluble)	all	all	most	most	most	Group IA Group IIA NH_4^+	Group IA NH_4^+ Sr^{2+} Ba^{2+} Tl^+	Group IA NH_4^+
Solubility less than 0.1 mol/L (slightly soluble)	none	none	Ag^+ Hg^+	Ag^+ Pb^{2+} Hg^+ Cu^+ Tl^+	Ca^{2+} Sr^{2+} Ba^{2+} Ra^{2+} Pb^{2+} Ag^+	most	most	most

FLAME COLOURS OF ELEMENTS

ELEMENT	SYMBOL	COLOUR
lithium	Li	red
sodium	Na	yellow
potassium	K	violet
rubidium	Rb	violet
cesium	Cs	violet
calcium	Ca	red
strontium	Sr	red
barium	Ba	yellow-green
copper	Cu	blue-green
boron	B	green
lead	Pb	blue-white

COLOUR CHART OF COMMON AQUEOUS IONS

ION	SYMBOL	COLOUR
chromate	CrO_4^{2-}	yellow
chromium(III)	Cr^{3+}	green
chromium(II)	Cr^{2+}	blue
cobalt(II)	Co^{2+}	pink
copper(I)	Cu^+	green
copper(II)	Cu^{2+}	blue
dichromate	$Cr_2O_7^{2-}$	orange
iron(II)	Fe^{2+}	pale green
iron(III)	Fe^{3+}	pale yellow
manganese(II)	Mn^{2+}	pale pink
permanganate	MnO_4^-	purple
nickel(II)	Ni^{2+}	light green

STANDARD ELECTRODE POTENTIALS FOR 1.0 mol/L SOLUTIONS AT 298.15 K (25°C)

Reduction Half-Reaction	Electrical Potential (V)
$F_{2(g)} + 2\,e^- \rightarrow 2\,F^-_{(aq)}$	+2.87
$PbO_{2(s)} + SO_4^{2-}{}_{(aq)} + 4\,H^+_{(aq)} + 2\,e^- \rightarrow PbSO_{4(s)} + 2\,H_2O_{(l)}$	+1.69
$MnO_4^-{}_{(aq)} + 8\,H^+_{(aq)} + 5\,e^- \rightarrow Mn^{2+}_{(aq)} + 4\,H_2O_{(l)}$	+1.51
$Au^{3+}_{(aq)} + 3\,e^- \rightarrow Au_{(s)}$	+1.50
$ClO_4^-{}_{(aq)} + 8\,H^+_{(aq)} + 8\,e^- \rightarrow Cl^-_{(aq)} + 4\,H_2O_{(l)}$	+1.39
$Cl_{2(g)} + 2\,e^- \rightarrow 2\,Cl^-_{(aq)}$	+1.36
$Cr_2O_7^{2-}{}_{(aq)} + 14\,H^+_{(aq)} + 6\,e^- \rightarrow 2\,Cr^{3+}_{(aq)} + 7\,H_2O_{(l)}$	+1.33
$2\,HNO_{2(aq)} + 4\,H^+_{(aq)} + 4\,e^- \rightarrow N_2O_{(g)} + 3\,H_2O_{(l)}$	+1.30
$O_{2(g)} + 4\,H^+_{(aq)} + 4\,e^- \rightarrow 2\,H_2O_{(l)}$	+1.23
$MnO_{2(s)} + 4\,H^+_{(aq)} + 2\,e^- \rightarrow Mn^{2+}_{(aq)} + 2\,H_2O_{(l)}$	+1.22
$Br_{2(l)} + 2\,e^- \rightarrow 2\,Br^-_{(aq)}$	+1.07
$Hg^{2+}_{(aq)} + 2\,e^- \rightarrow Hg_{(l)}$	+0.85
$ClO^-_{(aq)} + H_2O_{(l)} + 2\,e^- \rightarrow Cl^-_{(aq)} + 2\,OH^-_{(aq)}$	+0.84
$Ag^+_{(aq)} + e^- \rightarrow Ag_{(s)}$	+0.80
$NO_3^-{}_{(aq)} + 2\,H^+_{(aq)} + e^- \rightarrow NO_{2(g)} + H_2O_{(l)}$	+0.80
$Fe^{3+}_{(aq)} + e^- \rightarrow Fe^{2+}_{(aq)}$	+0.77
$O_{2(g)} + 2\,H^+_{(aq)} + 2\,e^- \rightarrow H_2O_{2(l)}$	+0.70
$I_{2(s)} + 2\,e^- \rightarrow 2\,I^-_{(aq)}$	+0.54
$O_{2(g)} + 2\,H_2O_{(l)} + 4\,e^- \rightarrow 4\,OH^-_{(aq)}$	+0.40
$Cu^{2+}_{(aq)} + 2\,e^- \rightarrow Cu_{(s)}$	+0.34
$SO_4^{2-}{}_{(aq)} + 4\,H^+_{(aq)} + 2\,e^- \rightarrow H_2SO_{3(aq)} + H_2O_{(l)}$	+0.17
$Sn^{4+}_{(aq)} + 2\,e^- \rightarrow Sn^{2+}_{(aq)}$	+0.15
$S_{(s)} + 2\,H^+_{(aq)} + 2\,e^- \rightarrow H_2S_{(aq)}$	+0.14
$AgBr_{(s)} + e^- \rightarrow Ag_{(s)} + Br^-_{(aq)}$	+0.07
$2\,H^+_{(aq)} + 2\,e^- \rightarrow H_{2(g)}$	0.00
$Pb^{2+}_{(aq)} + 2\,e^- \rightarrow Pb_{(s)}$	−0.13
$Sn^{2+}_{(aq)} + 2\,e^- \rightarrow Sn_{(s)}$	−0.14
$AgI_{(s)} + e^- \rightarrow Ag_{(s)} + I^-_{(aq)}$	−0.15
$Ni^{2+}_{(aq)} + 2\,e^- \rightarrow Ni_{(s)}$	−0.26
$Co^{2+}_{(aq)} + 2\,e^- \rightarrow Co_{(s)}$	−0.28
$PbSO_{4(s)} + 2\,e^- \rightarrow Pb_{(s)} + SO_4^{2-}{}_{(aq)}$	−0.36
$Se_{(s)} + 2\,H^+_{(aq)} + 2\,e^- \rightarrow H_2Se_{(aq)}$	−0.40
$Cd^{2+}_{(aq)} + 2\,e^- \rightarrow Cd_{(s)}$	−0.40
$Cr^{3+}_{(aq)} + e^- \rightarrow Cr^{2+}_{(aq)}$	−0.41
$Fe^{2+}_{(aq)} + 2\,e^- \rightarrow Fe_{(s)}$	−0.45
$NO^{2-}_{(aq)} + H_2O_{(l)} + e^- \rightarrow NO_{(g)} + 2\,OH^-_{(aq)}$	−0.46
$Ag_2S_{(s)} + 2\,e^- \rightarrow 2\,Ag_{(s)} + S^{2-}_{(aq)}$	−0.69
$Zn^{2+}_{(aq)} + 2\,e^- \rightarrow Zn_{(s)}$	−0.76
$2\,H_2O_{(l)} + 2\,e^- \rightarrow H_{2(g)} + 2\,OH^-_{(aq)}$	−0.83
$Cr^{2+}_{(aq)} + 2\,e^- \rightarrow Cr_{(s)}$	−0.91
$Se_{(s)} + 2\,e^- \rightarrow Se^{2-}_{(aq)}$	−0.92
$SO_4^{2-}{}_{(aq)} + H_2O_{(l)} + 2\,e^- \rightarrow SO_3^{2-}{}_{(aq)} + 2\,OH^-_{(aq)}$	−0.93
$Al^{3+}_{(aq)} + 3\,e^- \rightarrow Al_{(s)}$	−1.66
$Mg^{2+}_{(aq)} + 2\,e^- \rightarrow Mg_{(s)}$	−2.37
$Na^+_{(aq)} + e^- \rightarrow Na_{(s)}$	−2.71
$Ca^{2+}_{(aq)} + 2\,e^- \rightarrow Ca_{(s)}$	−2.87
$Ba^{2+}_{(aq)} + 2\,e^- \rightarrow Ba_{(s)}$	−2.91
$Li^+_{(aq)} + e^- \rightarrow Li_{(s)}$	−3.04

ACID-BASE INDICATORS AT 298.15 K (25°C)

INDICATOR	SUGGESTED ABBREVIATION	pH RANGE	COLOUR CHANGE AS pH INCREASES
methyl violet	HMv	0.0 –1.6	yellow to blue
thymol blue	H_2Tb HTb^-	1.2 – 2.8 8.0 – 9.6	red to yellow yellow to blue
cresol red	H_2Cr HCr^-	0.2 – 1.8 7.2 – 8.8	red to yellow yellow to red
orange IV	HOr	1.4 – 2.8	red to yellow
methyl orange	HMo	3.2 – 4.4	red to yellow
bromocresol green	HBg	3.8 – 5.4	yellow to blue
litmus	HLt	4.5 – 8.3	red to blue
methyl red	HMr	4.8 – 6.0	red to yellow
chlorophenol red	HCh	5.2 – 6.8	yellow to red
bromothymol blue	HBb	6.0 – 7.6	yellow to blue
phenol red	HPr	6.6 –8.0	yellow to red
phenolphthalein	HPh	8.2 – 10.0	colourless to pink
thymolphthalein	HTh	9.4 – 10.6	colourless to blue
alizarin yellow R	HAy	10.1 – 12.0	yellow to red
indigo carmine	HIc	11.4 – 13.0	blue to yellow
1,3,5–trinitrobenzene	HNb	12.0 – 14.0	colourless to orange

RELATIVE STRENGTHS OF ACIDS AND BASES AT 298.15 K (25°C)

ACID NAME	ACID FORMULA	CONJUGATE BASE FORMULA	K_a
perchloric acid	$HClO_{4(aq)}$	$ClO_{4\ (aq)}^-$	very large
hydroiodic acid	$HI_{(aq)}$	$I^-_{(aq)}$	3.2×10^{9}
hydrobromic acid	$HBr_{(aq)}$	$Br^-_{(aq)}$	1.0×10^{9}
hydrochloric acid	$HCl_{(aq)}$	$Cl^-_{(aq)}$	1.3×10^{6}
sulphuric acid	$H_2SO_{4(aq)}$	$HSO_{4\ (aq)}^-$	1.0×10^{3}
nitric acid	$HNO_{3(aq)}$	$NO_{3\ (aq)}^-$	2.4×10^{1}
hydronium ion	$H_3O^+_{(aq)}$	$H_2O_{(l)}$	—
oxalic acid	$HOOCCOOH_{(aq)}$	$HOOCCOO^-_{(aq)}$	5.4×10^{-2}
sulphurous acid ($SO_2 + H_2O$)	$H_2SO_{3(aq)}$	$HSO_{3\ (aq)}^-$	1.3×10^{-2}
hydrogen sulphate ion	$HSO_{4\ (aq)}^-$	$SO_{4\ (aq)}^{2-}$	1.0×10^{-2}
phosphoric acid	$H_3PO_{4(aq)}$	$H_2PO_{4\ (aq)}^-$	7.0×10^{-3}
orange IV	$HOr_{(aq)}$	$Or^-_{(aq)}$	$\sim \times 10^{-3}$
nitrous acid	$HNO_{2(aq)}$	$NO_{2\ (aq)}^-$	7.2×10^{-4}
hydrofluoric acid	$HF_{(aq)}$	$F^-_{(aq)}$	6.6×10^{-4}
methanoic acid	$HCOOH_{(aq)}$	$HCOO^-_{(aq)}$	1.8×10^{-4}
methyl orange	$HMo_{(aq)}$	$Mo^-_{(aq)}$	$\sim \times 10^{-4}$
benzoic acid	$C_6H_5COOH_{(aq)}$	$C_6H_5COO^-_{(aq)}$	6.3×10^{-5}
hydrogen oxalate ion	$HOOCCOO^-_{(aq)}$	$OOCCOO^{2-}_{(aq)}$	5.4×10^{-5}
ethanoic (acetic) acid	$CH_3COOH_{(aq)}$	$CH_3COO^-_{(aq)}$	1.8×10^{-5}
carbonic acid ($CO_2 + H_2O$)	$H_2CO_{3(aq)}$	$HCO_{3\ (aq)}^-$	4.4×10^{-7}
bromothymol blue	$HBb_{(aq)}$	$Bb^-_{(aq)}$	$\sim \times 10^{-7}$
hydrosulphuric acid	$H_2S_{(aq)}$	$HS^-_{(aq)}$	1.1×10^{-7}
dihydrogen phosphate ion	$H_2PO_{4\ (aq)}^-$	$HPO_{4\ (aq)}^{2-}$	6.3×10^{-8}
hydrogen sulphite ion	$HSO_{3\ (aq)}^-$	$SO_{3\ (aq)}^{2-}$	6.2×10^{-8}
hypochlorous acid	$HClO_{(aq)}$	$ClO^-_{(aq)}$	2.9×10^{-8}
phenol red	$HPr_{(aq)}$	$Pr^-_{(aq)}$	$\sim \times 10^{-8}$
phenolphthalein	$HPh_{(aq)}$	$Ph^-_{(aq)}$	$\sim \times 10^{-10}$
hydrocyanic acid	$HCN_{(aq)}$	$CN^-_{(aq)}$	6.2×10^{-10}
boric acid	$H_3BO_{3(aq)}$	$H_2BO_{3\ (aq)}^-$	5.8×10^{-10}
ammonium ion	$NH_{4\ (aq)}^+$	$NH_{3(aq)}$	5.8×10^{-10}
hydrogen carbonate ion	$HCO_{3\ (aq)}^-$	$CO_{3\ (aq)}^{2-}$	4.7×10^{-11}
indigo carmine	$HIc_{(aq)}$	$Ic^-_{(aq)}$	$\sim \times 10^{-12}$
hydrogen phosphate ion	$HPO_{4\ (aq)}^{2-}$	$PO_{4\ (aq)}^{3-}$	4.2×10^{-13}
dihydrogen borate ion	$H_2BO_{3\ (aq)}^-$	$HBO_{3\ (aq)}^{2-}$	1.8×10^{-13}
hydrogen sulphide ion	$HS^-_{(aq)}$	$S^{2-}_{(aq)}$	1.3×10^{-13}
hydrogen borate ion	$HBO_{3\ (aq)}^{2-}$	$BO_{3\ (aq)}^{3-}$	1.6×10^{-14}
water (55.5 mol/L)	$H_2O_{(l)}$	$OH^-_{(aq)}$	—

Note: An approximation may be used when the concentration of the acid is 1000 times greater than the K_a.

TEACHER QUESTIONNAIRE FOR CHEMISTRY 30

This is a course designed in a new distance-learning format, so we are interested in your responses. Your constructive comments will be greatly appreciated so that a future revision may incorporate any necessary improvements.

Teacher's Name _____ Area of Expertise _____

School Name _____ Date _____

Design

1. The modules follow a definite systematic design. Did you find it easy to follow?

   ❑ Yes ❑ No If no, explain.

   _____

   _____

2. Did your observations reveal that the students found the design easy to follow?

   ❑ Yes ❑ No If no, explain.

   _____

   _____

3. Did you find the Learning Facilitator's Manual helpful?

   ❑ Yes ❑ No If no, explain.

   _____

   _____

4. Part of the design involves stating the objectives in student terms. Do you feel this helped the students understand what they were going to learn?

   ❑ Yes ❑ No If no, explain.

   _____

   _____

5. The Learning Facilitator's Manual contains Assignment answers and a sample test. Did you find these helpful?

❑ Yes ❑ No If no, explain.

_____

_____

6. Did the Follow-up Activities prove to be helpful?

❑ Yes ❑ No If no, explain.

_____

_____

7. Were students motivated to try these Follow-up Activities?

❑ Yes ❑ No If no, give details.

_____

_____

8. Suggestions for computer and video activities are included in the course. Were your students able to use these activities?

❑ Yes ❑ No Comment on the lines below.

_____

_____

9. Were the assignments appropriate?

❑ Yes ❑ No If no, give details.

_____

_____

10. Did you fax assignments? ❑ Yes ❑ No

11. If you did fax, did you get satisfactory results from using this procedure?

❑ Yes ❑ No If no, give details.

_____

_____

Instruction

1. Did you find the instruction clear?

   ❑ Yes ❑ No If no, give details.

   _____

   _____

2. Did your observations reveal that the students found the instruction interesting?

   ❑ Yes ❑ No If no, give details.

   _____

   _____

3. Did you find the instruction adequate?

   ❑ Yes ❑ No If no, give details.

   _____

   _____

4. Was the reading level appropriate?

   ❑ Yes ❑ No If no, give details.

   _____

   _____

5. Was the work load adequate?

   ❑ Yes ❑ No If no, give details.

   _____

   _____

6. Was the content accurate and current?

   ❑ Yes ❑ No If no, give details.

   _____

   _____

7. Did the content flow consistently and logically?

❑ Yes ❑ No If no, give details.

_____

_____

8. Was the transition between booklets smooth?

❑ Yes ❑ No If no, give details.

_____

_____

9. Was the transition between print and media smooth?

❑ Yes ❑ No If no, give details.

_____

_____

Additional Comments

_____

_____

_____

_____

_____

_____

_____

_____

Thanks for taking the time to complete this survey. Your feedback is important to us.

Fax Number: 674-6686

Instructional Design and Development Unit
Alberta Distance Learning Centre
Box 4000
Barrhead, Alberta
T0G 2P0

Note: Please ensure that each of your students has completed and forwarded a copy of the Course Survey.

3 3286 50153 8090

Chemistry 30

Learning Facilitator's Manual

L.R.D.C.
Producer

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